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GEOLOGICAL-GEOTECHNICAL STUDIES FOR SITING THE SUPERCONDUCTING SUPER COLLIDER IN ILLINOIS

Results of the Fall 1984 Test Drilling Program

J. P. Kempton, R. A. Bauer, B. B. Curry, W. G. Dixon,
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FIGURES

TABLES

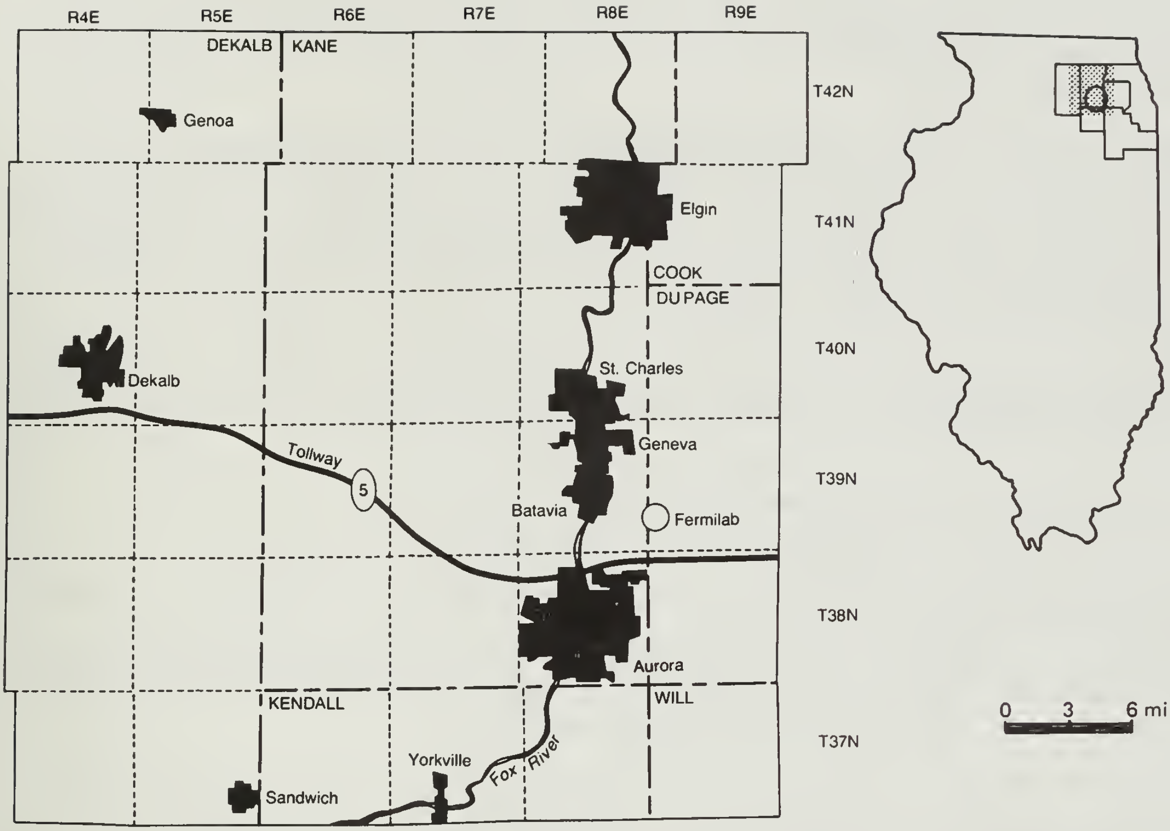

Figure 1 Study area in northeastern Illinois showing one possible ring configuration for the SSC.

ABSTRACT

More than 2,685 feet of NX wireline bedrock core and 150 split-spoon samples representing 947 feet of glacial drift were recovered from nine test holes drilled in Kane, Du Page, Kendall and De Kalb counties of northeastern Illinois. On-site observations established the lithology, drilling rate, fracture frequency, rock-quality designation, joint and fracture character of the bedrock, and blow counts and approximate unconfined compressive strength for the drift. Post-drilling operations included borehole testing for in-situ geophysical characteristics and permeability. Laboratory tests on bedrock included tensile strength, triaxial strength, and unconfined compressive strength; and on the drift, particle-size distribution and moisture content.

INTRODUCTION

In the fall 1984, test drilling began in northeastern Illinois to confirm existing information and establish baseline data on the stratigraphic, hydrogeologic, and geotechnical characteristics of the glacial materials and bedrock of the region. An Illinois State Geological Survey task force conducted this investigation—part of an extensive program to determine the geological and environmental suitability of northeastern Illinois for siting the proposed Superconducting Super Collider (SSC).

The siting studies are focusing on an area of 36 townships (approximately 1,300 square miles) including Kane County and parts of De Kalb, Cook, Du Page, Kendall, and Will Counties (fig. 1).

The study area lies about 30 miles west of downtown Chicago and extends mainly west of Batavia. One of the area's major facilities is Fermilab, which is an internationally recognized center for research in high-energy physics. The Tevatron, Fermilab's particle accelerator, could be the injector for the SSC.

Background for these studies has been presented in earlier reports. *Siting the Superconducting Super Collider in Illinois* was published by the Illinois Department of Energy and Natural Resources (DENR) in February 1985. Later in the year, the Illinois State Geological Survey published the results of the first phase of its investigation: *Geological-Geotechnical Studies for Siting the Superconducting Super Collider in Illinois: Preliminary Geological Feasibility Report* (ISGS Environmental Geology Notes 111, 1985).

These siting studies have been supported by the Governor and the General Assembly of Illinois through special appropriations. Site suitability is being evaluated both from an environmental and a geological perspective.

The geological-geotechnical program consists of four phases:

1. preliminary feasibility study (Kempton and others, 1985);
2. investigation of a selected region, including the Fermilab facilities, to locate the most suitable corridor for the SSC ring;
3. verification of predicted surface and subsurface conditions within the corridor and surrounding area by drilling test holes, and presentation of the results in a final geological feasibility report;
4. consultation services during the site selection process.

This report, part of phase 3, presents the preliminary results of the fall 1984 test drilling program. It provides a description of the procedures used for data collection, a summary of the results, and preliminary interpretations of the samples and other data collected from test holes F-1 through F-9. The detailed field logs and descriptions for all holes are on open file at the Illinois State Geological Survey. Laboratory test data will be on open file when analyses have been completed; and data not yet available will be summarized in subsequent reports. The spring 1985 test drilling program (Test Holes F-10 through F-17) will also be presented in another report.

GEOLOGIC SETTING

The geology of the proposed SSC site in northeastern Illinois is characterized by glacially deposited material lying above Paleozoic bedrock, including carbonates, shales, siltstones and some sandstones (fig. 2). Glacial drift thickness ranges from 0 to more than 500 feet. In De Kalb and Kane Counties, the bedrock surface is dissected by north-south or east-west trending valleys filled with glacial materials. The deepest of these is the Troy Bedrock Valley in western De Kalb County where the lowermost elevation of the bedrock surface is 450 feet. Bedrock units dip approximately 0.1°, to the southeast with the Ordovician Galena and Platteville Dolomite Groups exposed at the bedrock surface in De Kalb County (fig. 3). In western Kane County, these dolomite units are overlain by interbedded shale and dolomite of the Ordovician Maquoketa Shale Group, which are in turn overlain by dolomite formations of the Silurian System in eastern Kane and Du Page Counties. In the southwestern part of the study area lies a narrow zone (0.5 to 2 miles wide) of nearly vertical faults—the Sandwich Fault Zone (Kolata and others, 1978). The fault zone juxtaposes the Ordovician Galena and Platteville Dolomite Groups on the northeast side of the fault with Cambrian-aged rocks of Eminence, Potosi, and Franconia Formations on the southwest side.

The geologic setting of the study area is thoroughly discussed in the Preliminary Geologic Feasibility Study (Kempton and others, 1985) as well as the Handbook of Illinois Stratigraphy (Willman and others, 1975).

SYSTEM	SERIES	Group Formation	Graphic Log (Quaternary deposits above)	Description
SILURIAN	ALEXANDRIAN	Kankakee		Dolomite, fine grained
		Elwood Wilhelmi		Dolomite, fine grained, cherty
ORDOVICIAN	Cincinnatian	Maquoketa		Shale and interbedded dolomite
	CHAMPLAINIAN	Galena: Wise Lake		Dolomite, fine to medium grained
		Dunleith Guttenberg		Dolomite, fine to medium grained, cherty
		Platteville		Dolomite, very fine grained
		Ancell: Glenwood St. Peter		Sandstone, fine to medium grain, well sorted; dolomitic, poorly sorted at top
	Canadian	Prairie du Chien		Dolomite, cherty; little sandstone, siltstone, and shale
CAMBRIAN	CROIXAN	Eminence		Dolomite, fine to medium grained, sandy; contains oolitic chert
		Potosi		Dolomite, fine grained
		Franconia		Sandstone, fine grained, glauconitic
		Ironton–Galesville		Sandstone, dolomitic, fine to medium grained
		Eau Claire		Sandstone, siltstone, shale, and dolomite; glauconitic
		Mt. Simon		Sandstone, coarse grained, poorly sorted
		PRECAMBRIAN		Granite, red

Figure 2 Stratigraphy of bedrock units in northern Illinois (modified from Kempton and others, 1985).

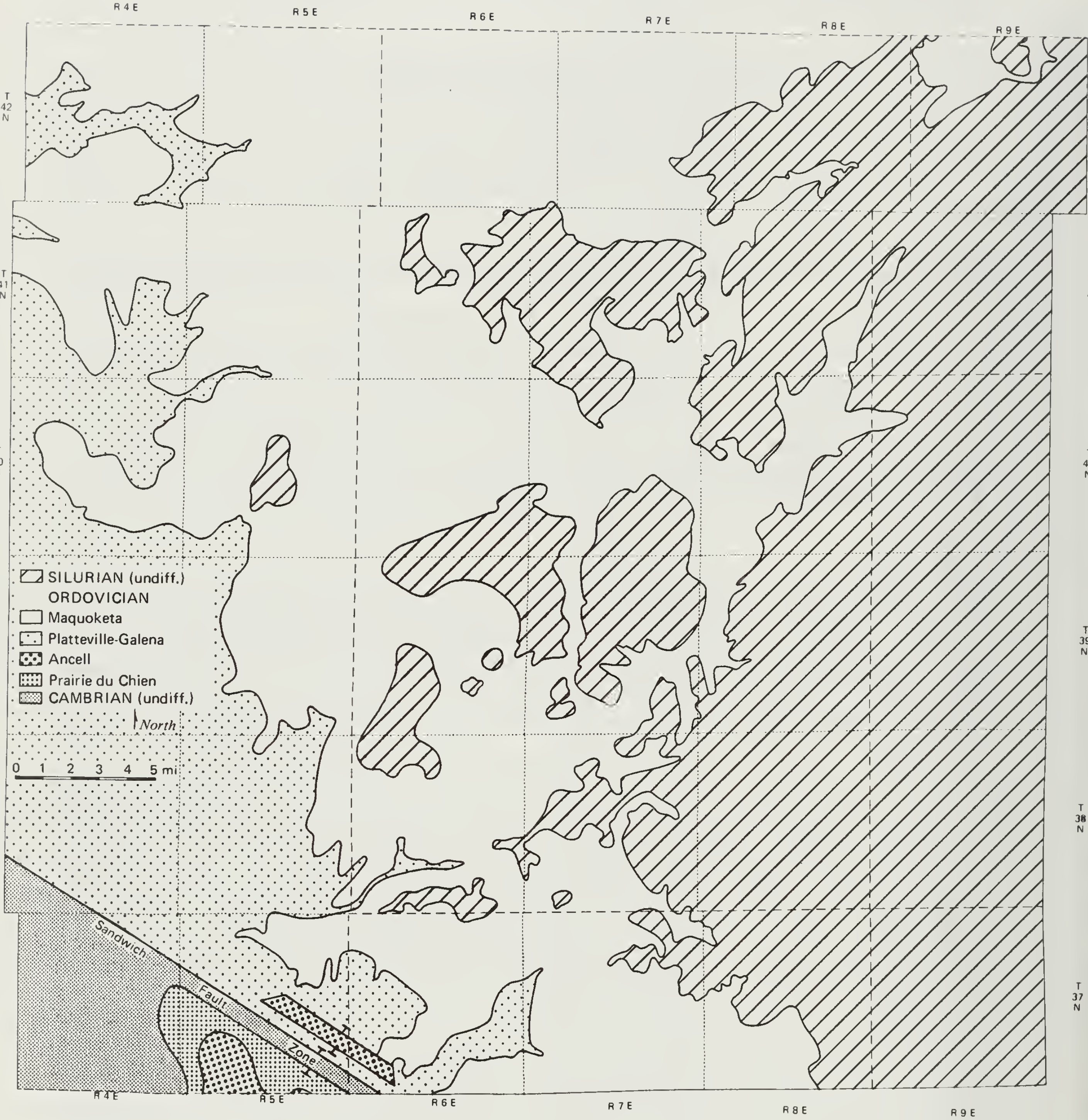

Figure 3 Geologic map of the bedrock surface.

Bedrock Stratigraphy
Of primary interest for the SSC siting are the rocks of the Kankakee, Elwood and Wilhelmi Formations (Silurian System), and the Maquoketa, Galena and Platteville Groups (Ordovician System) (fig.2).

Silurian System
The formations within the Silurian System in the study area consist primarily of light gray, fine-grained, thin- to medium-bedded dolomite with thin, green shaly partings. In some places, the Silurian has been completely eroded; thus it ranges from 0 to more than 100 feet thick.

Kankakee Dolomite light greenish and pinkish gray, pure, fine-grained dolomite that occurs in thin beds separated by wavy green shaly partings.

Elwood Dolomite brownish gray, cherty, and slightly more argillaceous dolomite. The Kankakee grades downward into the Elwood.

Wilhelmi Formation gray, argillaceous dolomite and dolomitic shale that fills channels cut into the underlying Maquoketa rocks. This erosional surface is irregular; thus thickness estimates of the underlying Maquoketa Group and Silurian strata are imprecise. In some instances, the Wilhelmi is difficult to distinguish from the Maquoketa Group due to lithologic similarities. This is particularly true in core and drill cuttings where the unconformity between the Wilhelmi and Maquoketa is not obvious. In such instances, the contact is usually selected on the basis of color; the shales of the Maquoketa Group are green in contrast to the typically gray shales of the Wilhelmi.

Ordovician System
The Prairie du Chien (Canadian; oldest), Ancell, Platteville, Galena (Champlainian) and Maquoketa Groups (Cincinnatian; youngest) are included within the Ordovician System. The Platteville, Galena, and Maquoketa Groups will be discussed in detail because of their relevance to the SSC siting. Buschbach (1964) contains discussions of the Prairie du Chien and Ancell Groups.

Maquoketa Shale Group green, brown, and red shale with minor fossiliferous carbonate. The Maquoketa Group ranges from 130 to 210 feet thick where overlain by Silurian formations within the study area. The Maquoketa is divided into the Neda, Brainard, Fort Atkinson, and Scales Formations from top (youngest) to bottom (oldest). In certain areas of the state, particularly in the SSC study area, these units are not easily distinguishable. The thickness and type of rock also varies considerably. Additional discussion of the Maquoketa Group is presented in Kolata and Graese (1983).

Neda Formation red, silty, hematitic shale containing flattened, concentrically layered spheroids. Within the study area, the Neda is absent due to pre-Silurian erosion. The Neda typically grades downward into the greenish gray shale of the Brainard.

Brainard Shale predominantly greenish gray, silty, fossiliferous, dolomitic shale interbedded with dolomite and limestone.

Fort Atkinson Dolomite light olive-gray to olive-gray, pure to argillaceous coarse-grained dolomite and limestone. The Fort Atkinson grades downward into the Scales Shale.

Scales Shale olive-gray, silty, dolomitic shale. There is generally a greenish gray shale zone at the base of the Scales; and the contact with the underlying Galena Group is abrupt.

SYSTEM	SERIES	STAGE	Formation	Member	Graphic Log	Interpretation of Materials
QUATERNARY	PLEISTOCENE	HOLOCENE	Cahokia			Alluvium–sand, silt, and clay deposited by streams
		HOLOCENE	Grayslake			Peat and muck, often interbedded with silt and clay
		HOLOCENE / WISCONSINAN	Richland			Loess–windblown silt and clay
		WISCONSINAN	Equality			Lake deposits–silt and clay, some sand
		WISCONSINAN	Henry			Outwash–sand and gravel in valleys and hills
		WISCONSINAN	Wedron	Wadsworth		Till–yellowish brown to gray silt and clay loam
		WISCONSINAN	Wedron	Haeger		Till–yellowish brown loamy; extensive, thick basal sand and gravel
		WISCONSINAN	Wedron	Yorkville		Till–yellowish brown to gray silt and clay loam
		WISCONSINAN	Wedron	Malden		Till–yellowish brown to brownish gray loams to sandy loam till; locally extensive basal sand and gravel
		WISCONSINAN	Wedron	Tiskilwa		Till–pinkish brown/grayish brown clay loam; generally uniform
		WISCONSINAN	Robein			Silt, sandy silt, silty clay, organic rich; buried soil, alluvium or bog deposits
		Sangamonian				
		ILLINOIAN	Glasford			Till, sand and gravel, lacustrine silt and clay; 8 till members recognized regionally; sand and gravel and lacustrine concentrated in bedrock valleys
		PRE–ILLINOIAN	Banner			Sand and gravel, basal materials in Troy Bedrock Valley
					Bedrock	

Figure 4 Stratigraphy of Quaternary deposits (chiefly glacial drift) in northern Illinois (modified from Kempton and others, 1985).

Galena and Platteville Dolomite Groups primarily gray to brown, fine- to medium-grained dolomite. The Galena Group is typically fine- to medium-grained, medium- to thick-bedded, and vuggy and vesicular in contrast to the underlying Platteville Group, which is fine-grained, thinner bedded, and less vuggy and porous. The Galena Group in the area is approximately 200 feet thick (where not eroded); the Platteville Group is 140 to 150 feet thick. Of particular importance within the Galena Group are thin beds of K-bentonite (altered volcanic ash) which are useful time-stratigraphic markers (Willman and Kolata, 1978).

The Galena Group is divided into three formations in this area. The uppermost Wise Lake Dolomite is composed of relatively pure carbonates; the underlying Dunleith Dolomite is cherty and more vuggy. The basal formation of the Galena is the Guttenberg Dolomite, which is characterized by reddish brown shale partings. The Platteville Dolomite Group is divided into a number of formations and members, but will not be discussed here. A detailed discussion of the Galena and Platteville Groups can be found in Willman and Kolata (1978).

Glacial Drift Stratigraphy

Glacially derived sediments (drift) of Quaternary age overlie an erosional topography on Paleozoic dolomite and shale. Figure 4 shows the stratigraphic succession. A discussion of glacial deposits of the region can be found in Kempton and others (1985); Berg, Kempton, and Stecyk (1984); and Berg and others (1985) who describe the Glasford Formation to the north of the study area. Preliminary work suggests many of these deposits can be traced into the study area. Kempton and others (1985) discuss the stratigraphy of post-Glasford sediments.

Samples of glacial drift were taken at 5-foot intervals where possible. Stratigraphic correlations with established units are to some extent based on sample color, particle-size analyses and clay mineral composition.

SUMMARY OF RESULTS: TEST-HOLE DESCRIPTIONS, DATA, AND INTERPRETATIONS

The location of each test hole (fig. 5, table 1) was selected to provide

- stratigraphic data (table 2) for areas where well-data control was limited or lacking
- geotechnical and hydrologic data on the geologic units lying between the surface and a potential tunnel elevation of about 400 feet within the zone that is most likely to contain the recommended corridor
- information for design and cost estimates.

This section includes all data available for each test hole, such as bedrock and drift stratigraphy, geophysical logging, pressure testing, and fracture spacing and orientation.

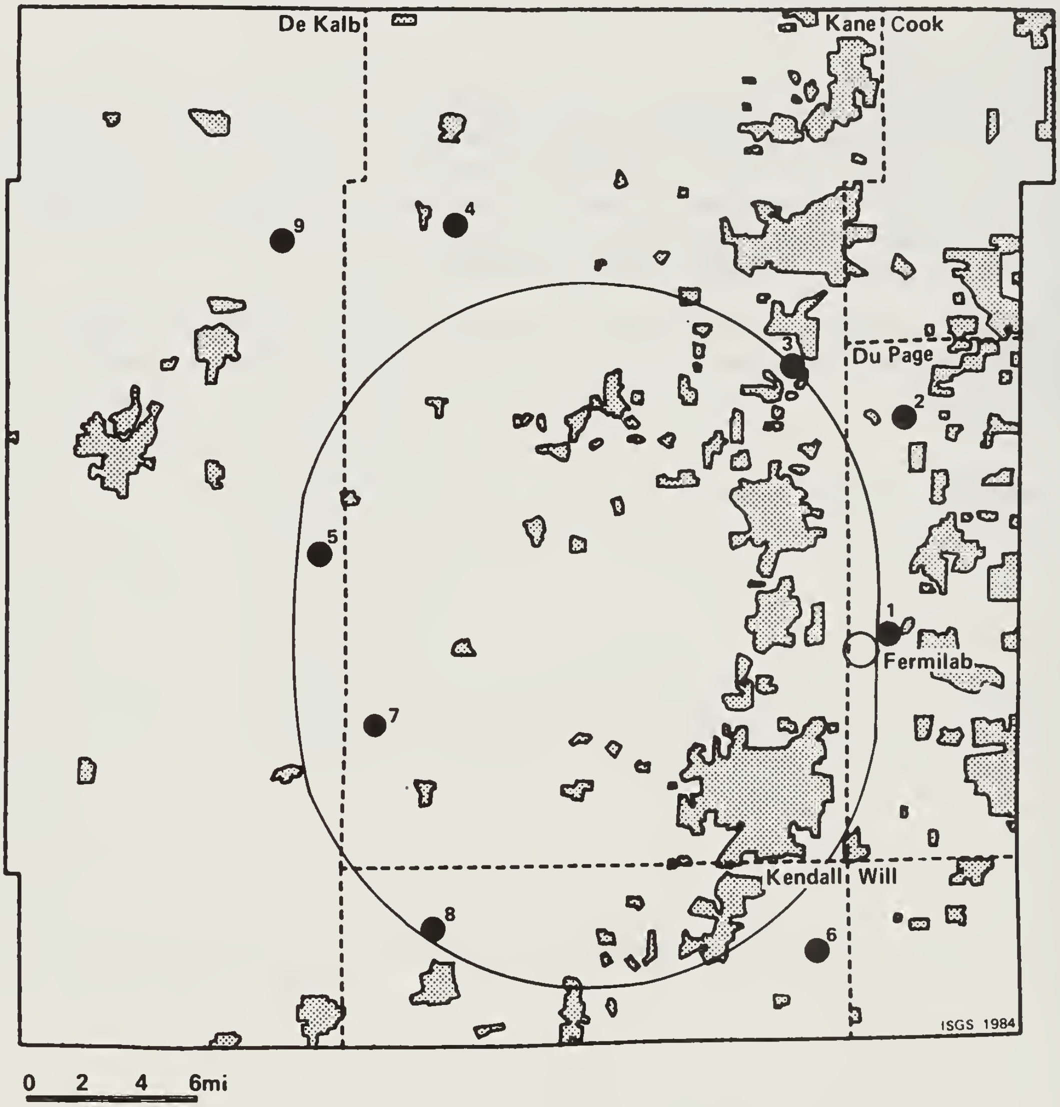

Figure 5 Test-hole locations of fall 1984 drilling program. The ring shown was one possible configuration used as a model for test drilling. Changes in the SSC design have reduced the size of the ring, so that proposed configurations no longer extend into De Kalb county. The stippled areas on the map are urban lands.

Table 1. Detailed location and elevation for each test hole

Hole no.	7½-minute quad	Engr. coor.	Location	Land surface elevation (±1 ft)
F-1	Naperville	4b	SW NW SW SE 20, T39N–R9E	739
F-2	West Chicago	1d	NE NE NE SE 17, T40N–R9E	785
F-3	Geneva	6b	SE NW SE SW 2, T40N–R8E	702
F-4	Hampshire	2c	SE SW NE SE 11, T41N–R6E	912
F-5	Maple Park	8b	SW NW SW SW 1, T39N–R5E	866
F-6	Aurora South	3f	NE NE SW NE 23, T37N–R8E	712
F-7	Big Rock	1h	NE NE NE NE 20, T39N–R6E	796
F-8	Plano	7a	SE SW SW 10, T37N–R6E	668
F-9	Genoa	1a	SW SE SE SE 10, T41N–R5E	917

Table 2. Test-hole summary, fall 1984 drilling, thickness of units (ft)

Hole no.	T.D.	Drift	Silurian	Maquoketa	Galena	Platteville	St. Peter
1	502.7	68.5	133.0	146.7	154.5	X	X
2	418.4	102.5	60.3	204.6	51.0	X	X
3	312.3	97.0	X	124.0	91.3	X	X
4	362.0	106.0	25.3	204.2	26.5	X	X
5	461.6	186.5	X	53.5	199.8	21.8	X
6	342.7	93.5	63.6	152.3	33.3	X	X
7	392.8	65.0	21.0	131.6	175.2	X	X
*8	319.5	44.8	X	149.1	125.6	X	X
9	492.4	156.5	X	88.6	196.4	50.9	X

* Angle hole drilled at 29.5° from vertical; numbers given are calculated vertical depth and thickness.

X Missing or not penetrated.

Bedrock Stratigraphy

Overall distribution and thickness of the rock units were as predicted on the basis of preliminary work by Kempton and others (1985) and earlier investigations (Buschbach, 1964; Willman, 1973; Willman and Kolata, 1978; and Kolata and Graese, 1983). Most of the Silurian formations and dolomite of the Galena and Platteville Groups are similar in lithology; the Maquoketa Group is quite variable in lithology and thickness. Except for Test Hole F-2, the rock types encountered in the Maquoketa Group in this study area do not correspond directly to those in Cook County where a typical lower shale (Scales Shale), middle carbonate (Fort Atkinson Dolomite) and an upper shale unit (Brainard Shale) are found. Rather, there appear to be several shale-carbonate successions, and the thicknesses of these units are non-uniform. These thickness variations may be due to variations in the topography of the surface on which these rocks were deposited during the Ordovician (Cincinnatian)—a topography partially reflected in the present structure of the top of the underlying Galena Group (Graese and Kolata, 1985). The Maquoketa Group will be discussed in later reports currently in preparation.

Glacial Drift Stratigraphy

The thickness and distribution of most stratigraphic units encountered during drilling were as indicated by Wickham (1979), Kemmis (1978), and Kempton and others (1985). In particular, the character and thickness of the Tiskilwa Till Member of the Wedron Formation are well documented (Wickham, Johnson, and Glass, 1987). Additional work is needed, however, to determine the stratigraphic position of thick, widespread sand and gravel bodies, especially in the southern half of the study area. Moreover, the stratigraphic and geomorphic relationships among deposits of the Wadsworth, Haegar, Yorkville, and Malden Till Members east of the Fox River and in the southern portion of the study area need further examination as suggested by Johnson and others (1985).

Of stratigraphic significance—although unrelated to siting the SSC—is an 8-foot thick organic-rich loam diamicton encountered between 88.5 and 96.5 feet depth in F-4. Two radiocarbon dates were obtained from this interval: 27,250 ± 340 years B.P. (88.50 to 88.75 feet; ISGS-1926) and 38,600 ± 340 years B.P. (93.50 to 93.70 feet; ISGS-1295). These ages span both the Farmdalian and Altonian Substages; considered together with other radiocarbon dates and stratigraphic relations, they may invalidate subsurface correlation of the late Altonian Capron Till Member of the Winnebago Formation in this area (Curry and Kempton, 1985).

Geophysical Logging

Significant log characteristics are presented in the order of completion. Test-hole summaries show only gamma-ray and neutron logs; all other log configurations are on open file at the Illinois State Geological Survey, Champaign.

■ Temperature Log

For these logs to accurately represent groundwater within the rocks, the water in the borehole should be at equilibrium with the surrounding rocks. Equilibrium may take several hours—or several months—to develop, depending on test-hole conditions. Due to time constraints, it was generally not possible to wait for complete equilibrium before temperature logging.

Borehole fluid temperatures ranged from 47.5° to 58.9°F (table 3). Cooler temperatures were generally encountered in the Silurian dolomites; warmer temperatures were found in the more shaly units and Galena and Platteville Groups.

Table 3. Temperature logs of water in boreholes taken by geophysical sonde

Hole no.	Since completion of boring (hrs)	Temperature range Low	High	Remarks
F-1	—	—	—	log *not* run
F-2	1	51.1	54.1	
F-3	63	56.0	58.0	log stopped at 256 ft due to obstruction
F-4	1/3	57.0	58.5	Sonde opening filled with drilling mud during part of run
F-5	1/2	56.0	58.0	
F-6	1	51.7	58.9	
F-7	1	51.6	58.9	
F-8	17	48.5	50.3	
F-9	1/2	NA	NA	

Table 4. Caliper log summary of boreholes

Hole no.	Diameter	Remarks
F-1	3.0 in. (0–503 ft)	lower 3 feet affected by cuttings
F-2	3.0 in. (0–418 ft)	
F-3	2.7 in. (136–312 ft)	washout zone at 129 feet
F-4	3.0 in. (0–69 ft) 3.15 in. (70–272 ft) 1.5 in. (272–308 ft) 1.5–2.5 in. (308–362 ft)	clay buildup inside of borehole?
F-5	3.0 in. (0–462 ft)	
F-6	3.0 in. (93.5–232 ft) 2.9 in. (232–280 ft) 2.4 in. (280–310 ft)	
F-7	3.0 in. (0–393 ft)	
F-8	3.0 in. (9–64 ft) 2.8 in. (64–319 ft)	
F-9	3.1 in. (0–96 ft) 2.8 in. (96–188 ft) 2.7 in. (188–238 ft) 2.6 in. (238–412 ft) 2.4 in. (412–492 ft)	

■ Caliper Log

The caliper logs demonstrate that the boreholes maintained a 3-inch diameter through most of the rock coring. Deviations from this norm are shown in table 4.

■ Self-Potential, Single-Point Resistivity, and Natural Gamma Logs

Galena and Platteville Dolomite Groups are characterized by high resistivity and generally low gamma radiation. Slight deflections towards higher gamma readings and lower resistivity indicate argillaceous dolomite. Very sharp peaks in this trend indicate bentonite beds, which are characteristic of the Galena Group (Kolata and others, 1984). On most logs, the Dygerts K-bentonite Bed (Willman and Kolata, 1978) was consistently found between 84 and 90 feet below the Galena/Maquoketa contact. A sharp peak on both self-potential and resistivity logs at the top of the Galena may be attributed to an electrical field within disseminated pyrite.

In the Maquoketa Shale Group, the Scales Shale has a characteristic reading for shale: low resistance and high gamma radiation. The lower contact between the Scales and Galena separates lithologies with nearly opposite electric-gamma log signatures. The upper contact scales with the overlying dolomite section is often gradational.

Fort Atkinson Dolomite consists of a nearly pure, fossiliferous dolomite, but is not clearly represented as a distinct layer in all of the logs. Rather, the logs and corresponding cores show that above the Scales, the abundance of dolomite beds generally increases upwards, as does the dolomite content in the shale, which is characteristic of the Brainard Shale in this area. The interbedded dolomitic shales and dolomite register an irregular, intermediate-intensity signature with an occasional high resistance peak indicating relatively pure dolomite.

The Elwood and Kankakee Dolomites (Silurian) cannot be consistently distinguished with these logs.

In summary, the Galena/Maquoketa contact, K-bentonite beds within the Galena, and the overlying Scales Shale have diagnostic electric- and gamma-log characteristics. The Silurian formations and the immediately underlying Maquoketa Group cannot be separated on the basis of these logs, but this is a consequence of similar lithologies. Drift character may be distinguished on the gamma logs , but sample control is necessary. In general, the higher clay content in till registers higher gamma emissions than do sand and gravel bodies. Especially useful in conjunction with these logs are interpretations of the neutron logs, which measure relative porosity below the water table.

■ Neutron Log

The configuration of this log generally corresponds to rock porosity below the water table. The highest bedrock porosities shown by these logs were generally in the thin to medium-thick beds of pure fossiliferous dolomite in the Maquoketa Group. Porous sand and gravel deposits in the drift also have pronounced signatures indicative of high porosities.

■ Density (Gamma-Gamma) Logs

These logs generally are a smooth curve suggesting similar rock density from glacial drift to bedrock. The Galena always has a signature indicating the greatest density. As the rock becomes more shaly, the log signature indicates lower density.

Hydrogeologic Data

■ Packer Tests

A total of 306 packer tests were conducted in 62 test intervals during the Fall 1984 Drilling Program. This equipment was capable of measuring the hydraulic conductivity of water in rock between 1.0×10^{-6} and 5.0×10^{-4} cm/sec. At values below 1.0×10^{-6} cm/sec., the flow was too low to measure, and at values above 5.0×10^{-4} cm/sec., a combination of factors produce measurements that were probably less than the true values. The highest permeabilities are consistently within the top 100 feet of bedrock, usually ranging from 10^{-3} to 10^{-4} cm/sec. Very low permeabilities were consistently found at the 400-foot elevation level (Dixon and others, 1985).

All packer-test data are presented in tables for each test-hole description . These data are also plotted on the graphic summaries for each hole; the range of the five tests per interval is plotted. Compare

Table 5a. Characteristics of piezometers installed in each borehole

Hole no.	Depth from ground surface (ft)	Elevation of top of slotted section (ft)	Length of slotted pipe (ft)	Stratigraphic unit; lithology
F-1	342	397	5	basal shale, Maquoketa Group; interbeds of shale and dolomite
F-2	377	408	5	as above
F-3	306	311	5	top of Galena Group; dolomite
F-4	no piezometer set			
F-5	460	406	5	top of Platteville Group; dolomite
F-6	300	412	5	base of Maquoketa Group; interbeds of shale and dolomite
F-7	389	407	5	Galena Group; dolomite
F-8	no piezometer set			
F-9	490	427	5	top of Platteville Group; dolomite

Table 5b. Water level data as measured in piezometers installed in boreholes (ft)

	F-1	F-2	F-3	F-5	F-6	F-7	F-9
Total depth	340	377	310	461	300	390	490
Land surface elev.	739	785	702	866	712	796	917
1984							
12–18	89.57	192.97	308.70	139.83	134.95	206.07	77.83
1985							
1–15	89.67	195.65	310.70	175.48	135.57	207.43	243.17
2–21		203.65					
2–22	89.47 89.60*				135.0 129.31*		
2–27	89.66						
2–28				174.43	129.83	205.63	243.04
4–1	88.21		310.70 309.39*	174.72	131.63	211.42	244.04 243.86*
4–30	87.88	243.69	310.70	175.01	132.04	206.60	244.02
5–10			**				
5–24	88.55		**	175.17	132.59	206.62	243.89
5–29		265.96	**				
6–21			**				
6–28	89.69	283.96	**		133.41	207.09	246.44
7–16			**	175.00		205.93	241.64
7–18	89.80	291.53	**		133.43		
8–19	90.21		**	175.31	134.72	206.33	
8–21		307.30	**				243.30
9–17	90.58	316.16	**	175.73	135.60	206.78	240.03
10–17	90.79	324.52	**	175.33	136.28	207.58	240.55
11–19	90.88	329.54	**	176.83	141.70	209.08	242.00
12–12	89.62	332.67	**	176.02	136.55	209.17	241.55
1986							
1–14	89.85	336.65	**	175.40	136.15	208.25	240.00

*Water level as measured after one quart of water was added to the well.
**Water level below the total depth of the well; not measured every month.

tabulated data with the graphs: a sequence of tests in which the values become successively lower suggests that fine-grained material may have progressively blocked waterflow paths. Conversely, a sequence of tests in which the permeability successively increases suggests that fine-grained material is washed out. Water leakage around packer bladders was strongly suspected when flow only occurred at the highest pressure in one set of tests (for example, in F-5 from 418–460 feet). Permeability of the glacial drift was not measured in this study.

■ Piezometers

Table 5a gives the depth of each piezometer, and the stratigraphic unit and lithology of the tested section. Table 5b lists water level readings taken at various times. Additional discussion of water levels is given in Kempton and others (Interim Geological Feasibility Report, in preparation).

Table 6. Summary of mean rock strength values per formation and group

Hole no.	Rock type	Qu (psi)	Modulus psi x 10*6	Indirect tensile strength (psi)	Axial point load index (psi)	Specific gravity	Shore hardness	Diameter point load index (psi)	Index of anistropy
Silurian									
F-1	dolomite	14,259	4.55	1,050	2,098	2.67	54	598	3.8
F-2	dolomite	15,529	9.30	1,248	2,600	2.74	65	747	3.5
F-4	dolomite	18,194	6.91	1,578	2,612	2.61	63	756	3.4
F-6	dolomite	18,825	6.68	1,130	2,185	2.70	54	613	3.7
F-7	dolomite	20,918	11.56	1,016	2,023	2.68	52	569	3.6
Average		16,341	7.20	1,178	2,299	2.69	58	656	3.6
Maquoketa									
F-1	dol-shale	4,457	0.98	537	724	2.53	26	218	3.7
F-2	dol-shale	3,662	0.59	401	479	2.43	28	145	3.7
F-3	dol-shale	3,996	0.56	519	827	2.43	24	295	3.5
F-4	dol-shale	3,608	0.82	458	664	2.54	26	165	4.3
F-5	dol-shale	4,277	0.52	669	768	2.38	25	94	8.7
F-6	dol-shale	5,133	1.10	554	679	2.48	25	150	5.5
F-7	dol-shale	5,299	0.65	637	1,258	2.59	32	564	2.7
F-9	dol-shale	6,654	1.12	684	898	2.62	41	344	2.8
Average		4,251	0.77	507	694	2.49	27	208	4.1
F-1	dolomite	10,024	3.34	953	1,551	2.69	47	524	3.1
F-2	dolomite	6,955	3.17	579	2,591	2.68	47	611	2.1
F-4	dolomite	8,755	2.72	860	1,427	2.45	55	477	3.3
F-6	dolomite	8,655	4.19	780	1,262	2.62	63	335	3.6
F-7	dolomite	10,083	2.65	757	814	2.61	45	199	4.3
Average		8,998	3.13	817	1,456	2.59	52	430	3.3
Galena (Wise Lake)									
F-1	dolomite	8,696	5.02	806	1,856	2.68	64	624	2.3
F-2	dolomite	11,342	5.58	958	1,423	2.69	65	525	3.3
F-3	dolomite	9,482	5.99	884	1,960	2.66	60	572	3.5
F-4	dolomite	9,538	6.27	861	1,446	2.67	59	467	3.3
F-5	dolomite	9,754	5.40	801	1,296	2.65	51	485	2.9
F-6	dolomite	10,168	4.59	973	1,748	2.65	58	582	3.2
F-7	dolomite	9,414	7.73	677	1,324	2.69	59	591	2.3
F-9	dolomite	11,330	6.47	719	983	2.54	50	410	2.5
Average		10,158	5.81	854	1,459	2.66	59	531	3.0
Galena (Dunleith)									
F-5	dolomite	7,193	4.54	768	1,256	2.57	42	445	2.9
F-7	dolomite	9,659	4.14	639	1,144	2.64	59	529	2.3
F-9	dolomite	9,163	6.01	626	1,015	2.55	52	441	2.6
Average		8,737	5.24	666	1,105	2.57	51	455	2.6
Platteville									
F-5	dolomite	10,262	6.56	835	1,452	2.56	49	498	3.2

Geotechnical Data

Joint characteristics and amount of dip of the joint planes have been documented in each borehole. The strike and spacing of joints were documented in the angle borehole F-8. The general conditions of the joints in the Galena are wavy, rough, nonweathered, tight, and contain no clay filling. They are also high angle (near vertical). Angle borehole F-8 showed the northwest joint set to be most prominent with a direction of about N 35° W and the northeast set at N 30° E to N 60° E. These joint directions closely match the directions found in Kane County (Foote, 1982), and the Calumet pump station (Shuri and Kelsay, 1984) and TARP tunnels (Weiss-Malik and Kuhn, 1979) to the east. The joint spacing found in angle borehole F-8 differed between the Maquoketa and Galena. The average spacing between both joint sets in the Maquoketa is about 7.95 feet while the joint spacing in the Galena is about 2.3 feet for the NW set and 2.6 feet for the NE set.

Laboratory strength testing of the cores from Test Holes F-1 through F-9 included unconfined and confined compression, indirect tension, axial and diametral point-load, moisture content, specific gravity, compressive-wave velocity, and shore hardness. Table 6 shows average strength and property values for the individual formations per borehole. The complete test results are on open file at the Illinois State Geological Survey.

GENERAL PROCEDURES

The drilling program included a plan for test hole locations and necessary drilling specifications. On the basis of competitive bidding, a drilling contract was awarded to D & G Drilling Inc., New Lenox, Illinois. The following statements briefly summarize the procedures followed for drilling and sampling each test hole:

1) Survey personnel located the drilling site, obtained permission from land owner to drill, checked the location of utilities, and located supply of water for drilling.
2) The driller set up drilling rig, using a Mobile B-56 for most holes. The drilling contractor provided an experienced driller and helper.
3) As requested by the Survey, the driller took split-spoon samples in drift (usually at 5-foot intervals). Survey geologists recorded blow counts (N values for standard penetration test), described materials and sampled cores for laboratory analysis.
4) The driller set casing into bedrock and diamond cored the bedrock using wireline drilling method with a 10-foot core barrel to take 1.87-inch-diameter continuous core.
5) Survey geologists described each length of core and noted the number and nature of fractures. Loss of circulation of drilling fluid and some water levels were also recorded during drilling. Selected samples were placed in plastic bags for future laboratory testing for strength, density, moisture content, etc. Two Survey geologists were normally present for this work.
6) Survey geophysicists logged each hole (consisting of four runs for 8 log configurations).
7) Survey geologists supervised packer testing (pressure tests of hole at regular and/or selected intervals), to check zones where drilling records indicated a loss of circulation occurred, where significant natural fractures were noted, and at elevation 400 feet (one of the proposed elevations selected for the SSC tunnel).
8) The driller installed a 1-inch-diameter plastic pipe from the ground surface to depth determined by the geologist. The lower 5 feet of the pipe was slotted and placed in position (approximately elevation 400 feet). A specified amount of pea gravel was poured into the hole to fill around the slotted portion; and finally, grout seals were poured above the pea gravel to isolate and seal the zone of observation.
9) The driller pulled the surface casing pipe and replaced it with a short section of pipe with a locking cap to protect the 1-inch plastic pipe.
10) The driller grouted the hole around the 1-inch plastic pipe to ground surface, and restored the site to pre-drilling conditions.

Geophysical Borehole Logging

Sensing devices are lowered into a well or other borehole to produce continuous records (graphs) of various rock properties of the borehole wall and the fluids that fill the borehole. The logs are used for correlation and characterization of various rock attributes. The Illinois State Geological Survey utilizes and conducts research with several combined types of geophysical logs run sequentially in the test holes: Temperature-Conductivity, Caliper, Spontaneous Potential, Single-Point Resistivity, Density, and Natural Gamma-Neutron.

Geophysical logging at the Illinois State Geological Survey is accomplished with a Log-Master 554-E carryall-mounted borehole logger, built by Log-Master International, Enid, Oklahoma. Logs are made using a sonde about 2 inches in diameter and of various lengths depending on the property to be measured. The sonde is lowered into the borehole attached to the end of the cable containing four electrical conductors. The cable is raised and lowered using a winch which has a depth measuring device to indicate the depth of the sonde. The electrical conductors are connected to an electrical control panel and chart recorder that records signals being returned from the logging tool. The following discussion describes each of the logs run. The log records are available on open file at the ISGS.

■ Temperature and Fluid Conductivity Log

The ISGS temperature and fluid conductivity probe is capable of detecting borehole temperatures to 1/50 of one degree from 15° to 212°F and conductivities equivalent to NaCl concentrations from less than 200 to over 50,000 mg/l.

Temperature logs are interpreted relative to the expectation of a "normal" geothermal gradient of about 1° increase in temperature per 100 feet of increased depth below the level of seasonal variations. Groundwater temperatures below the level of seasonal variations are approximately equal to the mean annual temperature in the area. In this part of northern Illinois the mean annual temperature is about 50°F.

■ Caliper Log

The caliper log, which measures borehole diameter, is the simplest of logs to run, record, and interpret. The caliper probe has a set of arms that are extended radially by a spring-loaded mechanism so they contact the borehole walls. The probe may show fractures, cavities or narrowing of the borehole. Changes in diameter, and casing depth and damage to existing wells may show as a change in diameter on the logs. This log is used to evaluate the condition of the borehole and to determine the advisability of running logs that require nuclear sources such as density and neutron logs. This probe is not affected by fluid in the borehole.

■ Electric Log

The probe senses both differences in electrical potential and the single-point resistivity which are graphically recorded and referred to simply as an electric log. In both cases a grounding electrode is placed in either the mud-pit or a small water-filled hole at the surface. The potential log is a measure of the potential difference among the rock materials. The single-point resistivity log shows the relative relationships of the electrical resistivity of the rock formations. These logs are primarily used for geologic correlation, to measure bed thickness, and for interpreting porosity of the rock in the wall of the borehole. In general, shale will cause deflections toward the middle on both these logs, because it has strongly positive potential and low resistivity due to the high degree of ionization of the clay particles in the shale. In this study, the basal shale of the Maquoketa Group has this characteristic. Dolomite of the Galena Group, by contrast, causes deflections toward the margins of the chart. Dolomite has low potential and high resistance to electrical current flow; sandstone is generally intermediate. Electric logging requires an uncased hole filled with fluid of low salinity.

■ Gamma-Ray Log

Natural-gamma logs are graphs of the amount of natural gamma radiation emitted by earth materials. Significant background solar radiation is eliminated by the blanket of earth, allowing the measurement of very low levels of radiation from potassium-40, uranium and thorium-232. These elements are most abundant in the clay minerals and much less concentrated in clean quartz sand, gravel, and pure carbonate rock. Both fluid filling and steel casing tend to dampen the levels of radiation, but relative levels are easily recognized. This log can be run under all normal borehole conditions.

The chief use of the gamma log is for stratigraphic correlation and identification of lithology. The sensitivity of the gamma probe is limited by the borehole diameter, the presence and type of fluid, the size and material of casing, and rock density. Most secondary gamma-ray photons are believed to originate from within 12 inches of the borehole wall. The scale settings and departure depicted on the gamma log can be calibrated in either API (American Petroleum Institute) units or counts per second.

■ Neutron Log

The neutron log indicates the concentration of hydrogen in the area surrounding the logging probe, by using a 3-curie americium-241/beryllium source, having a flux of 6.6 x 10^6 neutrons per second. These are high-energy neutrons (greater than 10^5 ev or 0.1 Mev) that pass through the walls of the source, fluid column, casing and rock and are slowed down to energies below 0.025 Mev (thermalized) by collisions with atomic nuclei. Hydrogen is the most effective element in reflecting neutrons because its nucleus has nearly the same mass as a neutron. Because the flux of these thermal neutrons is proportional to the amount of hydrogen present, and most of the hydrogen is present in water, the flux is proportional to the amount of water. When water fills interstitial pore space, the neutron log records relative rock porosity.

The principal limitation of the neutron log is that it cannot discriminate between hydrogen in pore water and hydrogen in the form of hydroxal ions (OH^-) principally found in clay minerals, the primary constituents of shales. As a result, shale and other formations containing minerals with hydrogen give readings similar to high porosity on neutron logs. The neutron logs of sandstone, limestone, and dolomite with very low contents of clay minerals, are good indicators of relative porosity.

The neutron log is normally run with a natural-gamma log to aid the interpreter in recognizing shaly formations. A caliper log is also essential in interpreting the neutron log, because changes in the volume of water surrounding the probe will produce changes in the level of thermal neutron flux.

■ Density Log (Gamma-Gamma Log)

The density log is a record of the approximate rock density determined by bombarding the rock with intense gamma radiation from a 0.125-curie cesium-137 source and measuring the amount of secondary emission from the rock. For this measurement, the flux is inversely proportional to the bulk density. Dense rock materials absorb much of the radiation emitted from the source, whereas less dense materials tend to generate higher levels of secondary emission received by the detector. Natural background gamma emissions are generally insignificant and do not effect the log. Since changes in borehole diameter may effect the log, a caliper log is a necessary supplement.

Hydrogeology

The hydrogeologic properties of the rock units are particularly important to engineering projects involving tunneling. Because the most suitable elevation to construct a tunnel lies mostly within the uniform Galena Group, special emphasis was given to characterize the hydraulic conductivity and piezometric head levels of the Galena Group and rocks and materials directly above and below. Data on hydraulic conductivity were determined by pressure (packer) tests while piezometers were set to permit measurement of piezometric heads at a proposed tunnel elevation. Overall evaluations of the hydrogeologic setting based on these and other data will be presented in subsequent reports. Data on fluid losses during drillling were recorded as were water levels in open drillholes prior to the resumption of drilling each morning.

■ Pressure Testing

Downhole pressure testing provides information on the in situ hydraulic conductivity of the rock units within the project area. A pair of pneumatically operated rubber packers or bladders separated by a perforated pipe are lowered into a drillhole to a predetermined depth. The packers are inflated to seal against the rock sidewalls; water is pumped into the rock interval between the packers at a steady pressure, and finally, rate of water flow is measured. The equipment

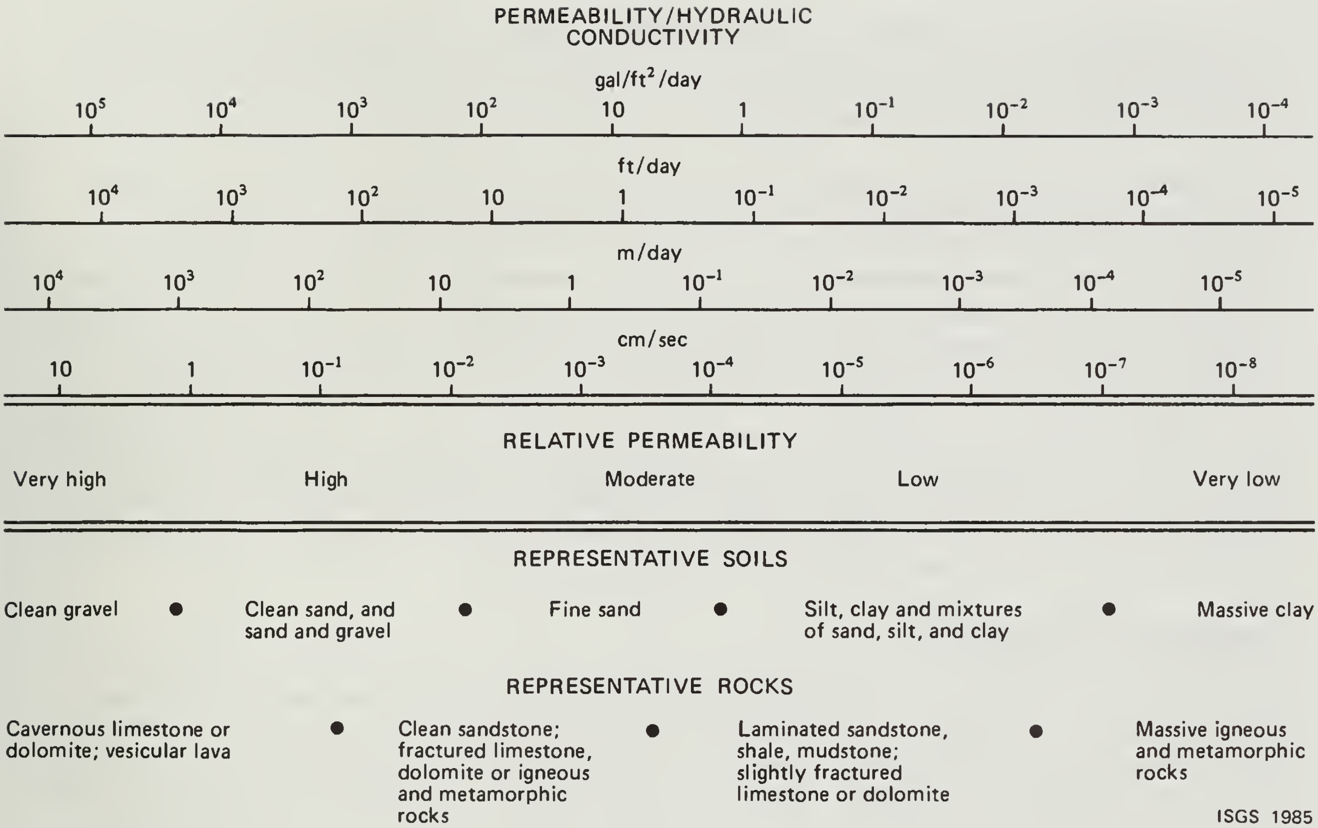

Figure 6 Permeability/hydraulic conductivity chart (modified from the U.S. Dept. of Interior Groundwater Manual, 1981).

used for these particular tests is sensitive to hydraulic conductivities no lower than about 1 x 10^{-7} cm/sec. The data recorded during the tests are used to calculate an approximate permeability value which may be an indicator of expected water flow. These data will be used in the engineering cost study to calculate pumping and construction costs for the proposed tunnel. A graphic comparison of four commonly used units of hydraulic conductivity is shown in figure 6. This figure also indicates relative terms associated with different ranges of values and also lists representative earth materials and rock types below their commonly measured ranges of values.

Theoretically the hydraulic conductivity of a given rock should be constant at different pressures; however, this is not always found to be the case in the field. Accordingly, a five-step, "up and down" (increase and decrease), sequence of pressures for each test interval is used in this study. Some of the factors which can affect the results of pressure tests are: the type of flow, laminar or turbulent; erosion of fines and plugging of the formation; erosion and wash-out of fines to increase permeability; hydrostatic uplift and increase of permeability; friction loss in the pipes; leakage around a packer; and rupture of a packer.

A standardized procedure was adopted for this program so that the data from the holes could be more easily compared. Below a depth of 150 feet the tests were run in succession at a given test interval at pressures of 35 psi, 70 psi, 100 psi, 70 psi and 35 psi. Above a depth of 150 feet the pressures used were 10 psi, 30 psi, 50 psi, 30 psi, and 10 psi. These pressures will not cause hydrostatic uplift.

Prior to pressure testing, the equipment was calibrated by Mr. David Frey of Harza Engineering Company, Chicago, to determine the amount of pressure loss in the pipe system due to the frictional drag between the wall of the pipe and the water. Packers were set 21 feet apart; thus measurements were made in selected 21-foot intervals of rock in each test hole.

The pneumatic pressure (gage, at ground surface) applied to the packers is based on the depth of the bottom packer and is the sum of four pressures: Gage (the maximum water pressure to be applied to a test interval) plus Column (the depth of the water table times 0.433) plus Hydrostatic (the distance from the water table to the lower packer times 0.433) plus Set (an arbitrary number, 40, selected from experience to seal the packer firmly against the rock wall without rupturing the rock or packer bladder). Figure 7 is an example of the water pressure test form we used in the field supplied by representatives of Harza Engineering Company.

The extent of testing in a given boring will depend on the condition of the rock as determined from an examination of the core and on the relative amounts of fluid return with respect to depth during the drilling operation. The first boring (F-1) on Fermilab property was tested for the entire rock interval to provide comparative background data for all rock units encountered there, and selected intervals have been tested in the remaining borings.

Installation of Piezometers

A standing-water-level Casagrande (head) type piezometer (fig. 8) was installed in most holes to make long-term observations of the water pressure at one proposed tunnel elevation, 400 feet above sea level. The installation consisted of placing and sealing a plastic pipe within permeable backfill material opposite the zone to be tested. The pipe is slotted only in the 5-foot test section. Above the test section (and below when the piezometer was not placed at the bottom of the hole), space between the borehole walls and the pipe was sealed with grout. To insure integrity of the seal, the grout was pumped into the hole through a tremie pipe kept below the surface of the grout. The water level in the pipe equilibrates with the pore-water pressure of the test section and is measured using an electric drop line. The top of the plastic pipe is protected by a short section of surface casing cemented in place and locked with a protective cap.

Engineering Geology

Bedrock: Field Procedures

Information on the attitude and spacing of rock fractures and rock strength data are important for determining the excavation method and the suitability of rock units to house underground tunnels and chambers.

Some engineering geology and bedrock information is recorded in the field on two forms (figs. 9a, b). The first form (fig. 9a) is used to record general information about both glacial drift and bedrock as well as to record standard drilling information and to describe specific features and core characteristics such as joints, fractures, standard penetration test, blow counts, core recovery, RQD (Rock Quality Designation), fracture frequency and bed spacing. The second form (fig. 9b) is used to show other physical attributes of the core such as the depths and spacing of rock discontinuities and features of these discontinuities in detail.

Drilling rate During drilling, the average time taken to core through each foot of rock is recorded in minutes. Generally, drilling through massive shaly units (such as the base of the Maquoketa Group), or cherty horizons is slower than drilling through massive carbonate rock.

Core recovery Each run of the core barrel is advanced a measured distance (usually about 10 feet by the driller; core recovery is calculated as the total length of core collected in the core barrel divided by the length of the run. Less than 100 percent core recovery may be caused by voids, or if the rock is so fractured, pieces of core are ground up and lost during drilling.

WATER PRESSURE TEST

HOLE NO. ________

PROJECT ______________________________ Sheet ____ of ____

LOCATION SKETCH

Hole Location ______________ Coordinates: N ______________

Angle (From Horizontal) ________ E ______________

Bearing ______________ Ground Elevation ______________

Hole Size ______________ Depth to Bedrock (down–hole) ________

Total Depth of Hole ________ Water Depth Before Testing:

Tested by ______________ Inclined ______ Vert. ______

Date Tested ______________ Height of Gauge Above Ground ________

Test Number	INTERVAL TESTED (–ft.) (–m.)			TAKE (–cu. ft.) (–gal.) (–liters) / min.					PRESSURE (–psi) (–Kg/cm²)				PERMEABILITY
	From	To	Length	Meter		Water Loss	Elapsed Time (min)	Take	Gauge (+)	Column (+)	Friction Loss (–)	Net	(Units)
				Start	End								

REMARKS:

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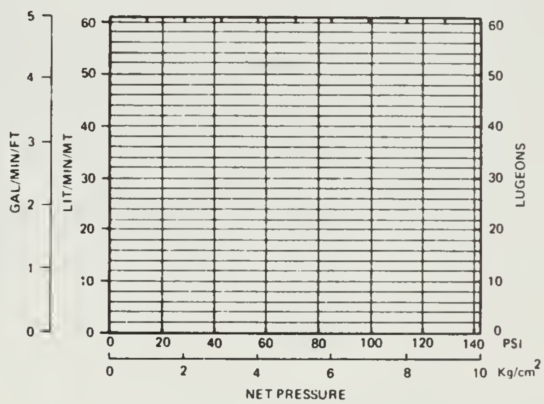


Figure 7 Water pressure testing form (from Harza Engineering Company).

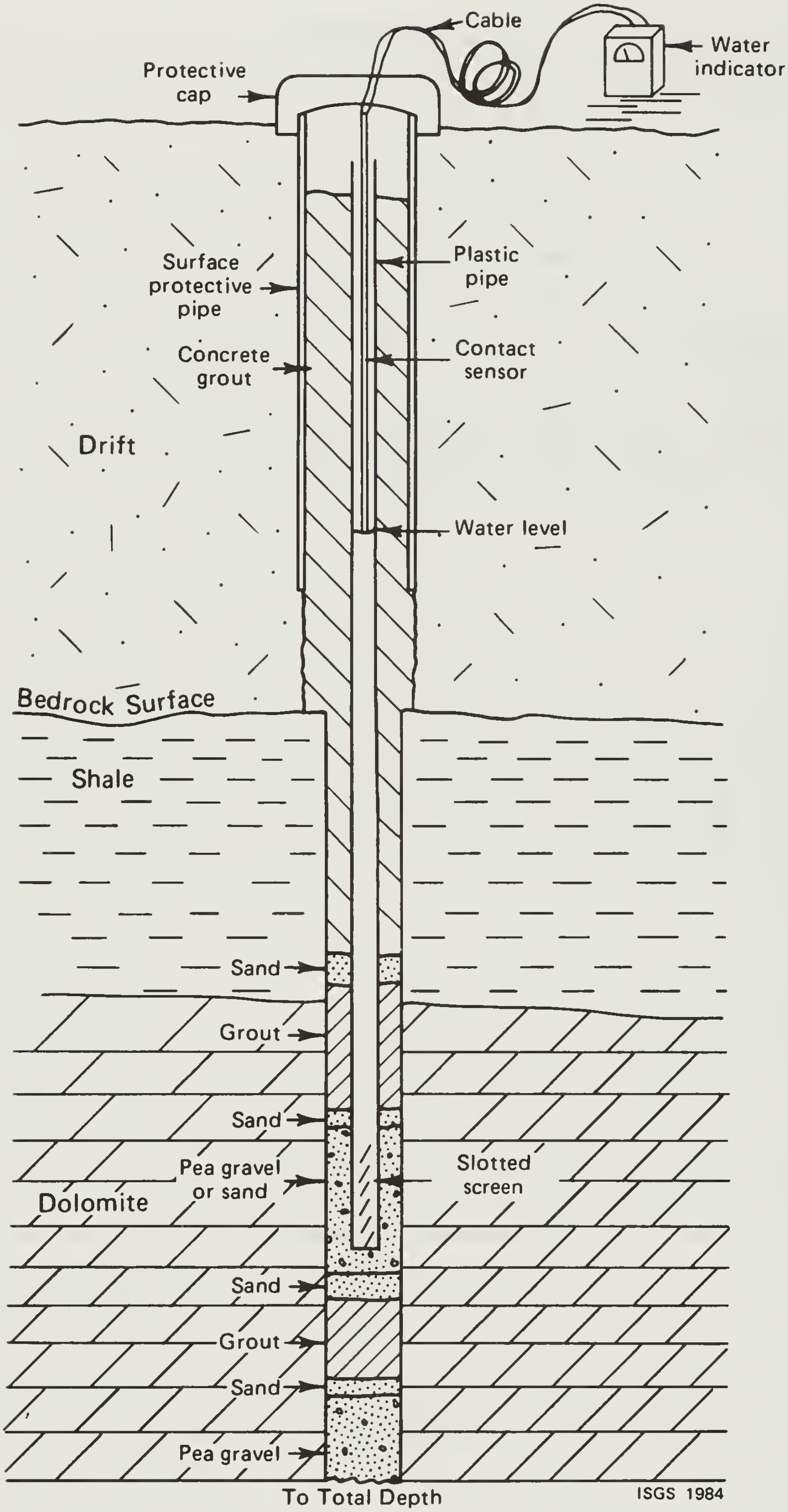


Figure 8 Standing-water-level piezometer design.

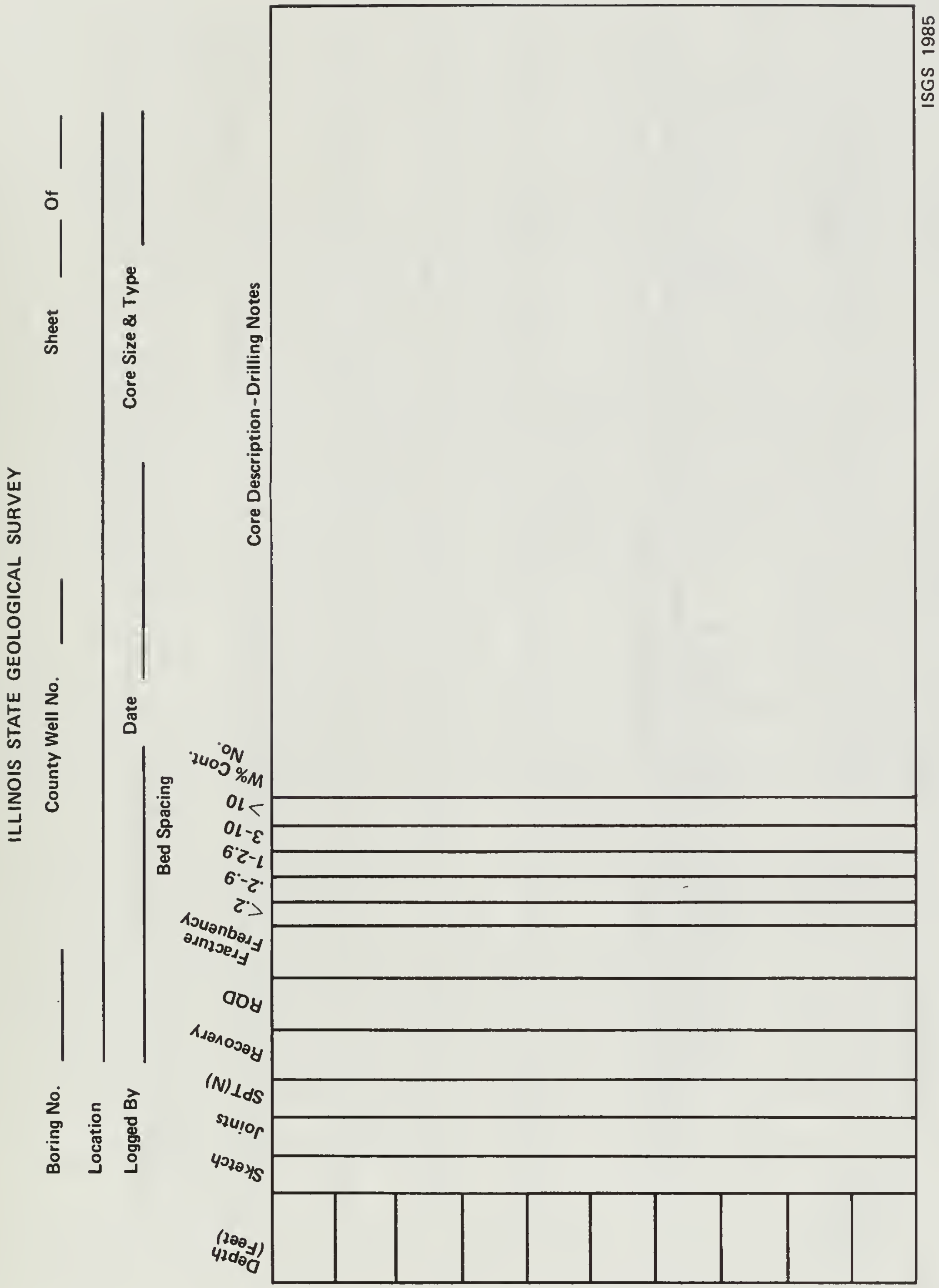


Figure 9a Example of field drilling-log form.

ROCK DISCONTINUITY LOG

County Well No. ____

Boring No.	Logged by:	Date:	Depth	Sheet of

GENERAL					FILLING																				ROCK PLANES										REMARKS
	Discont. Type				AMT.			COLOR							TYPE						CONSIST.					COND.				ROUGHNESS					
Depth (ft)	Bedding	Joint	Dip (°) from Horizontal	Width (ft)	None	Partial	Complete	Black	Gray	Green	Brown	Red	Yellow	Other	Shale	Clay	Mineralized	Healed	Mineral Type	Other	Soft	Hard	Crumbly	Fissile	Slickensided	Sound	Altered	Very Altered	Staining	Planar	Wavy	Uneven	Rough	Smooth	Slickensided

Figure 9b Example of rock discontinuity log.

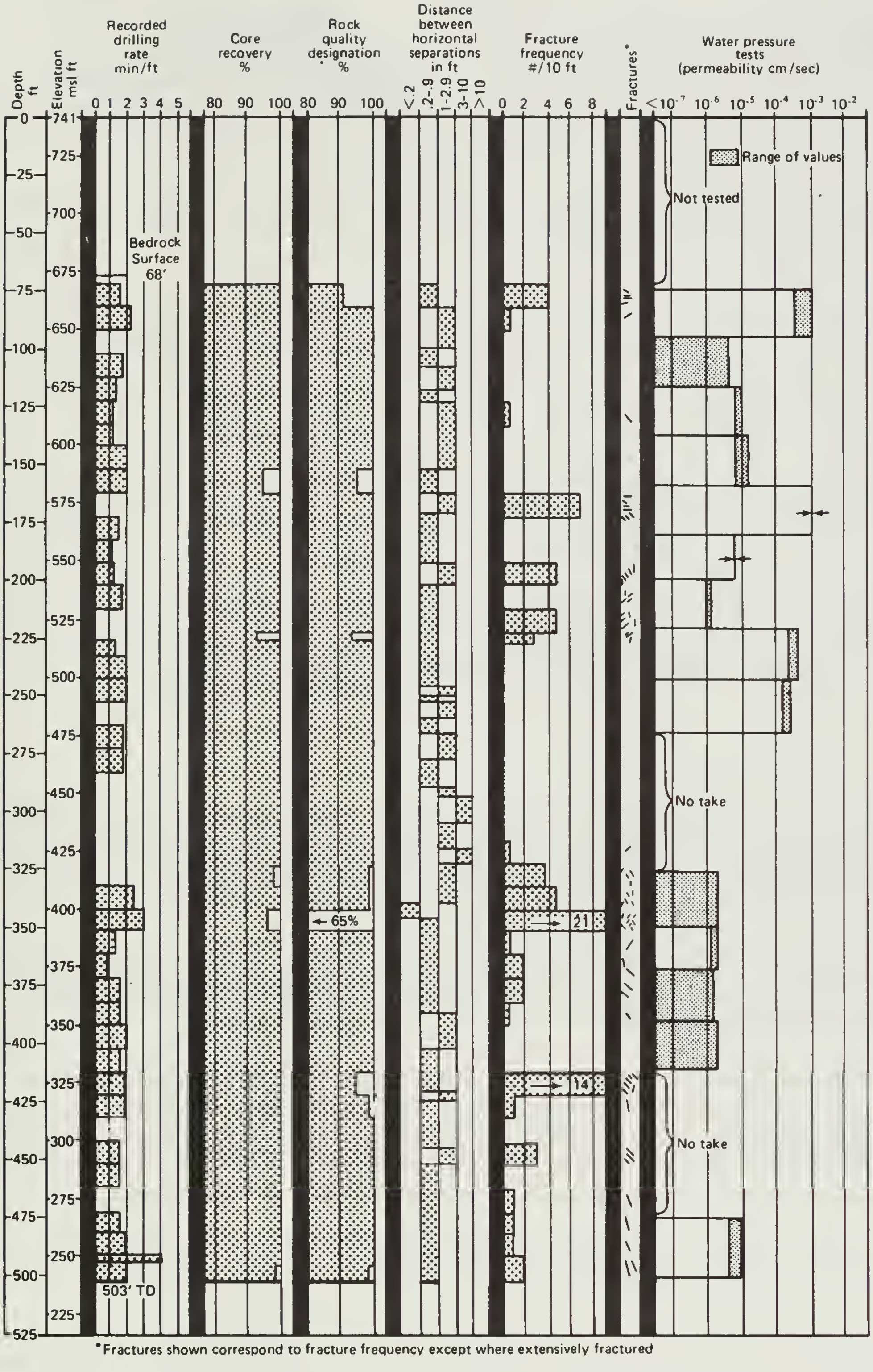


Figure 10 Summary diagram of drilling, core, and borehole characteristics.

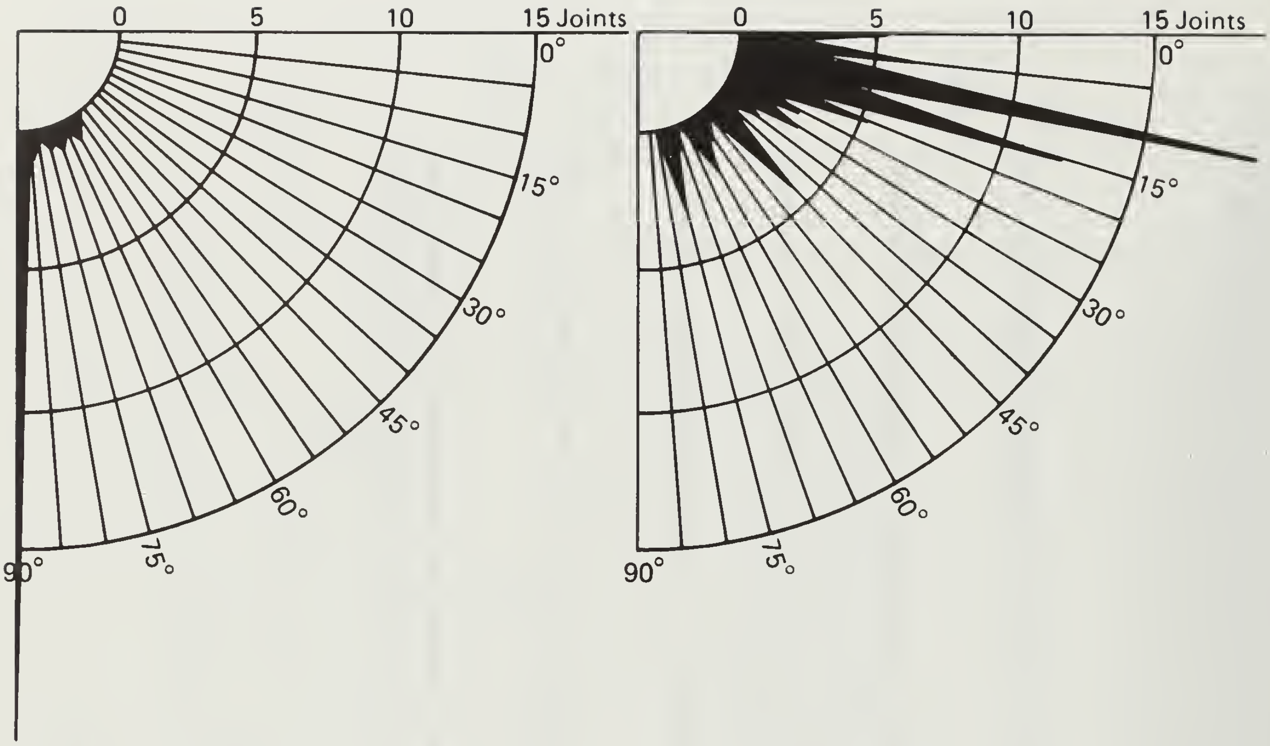


Figure 11 Examples of method used to show number and angle of dip of joints.

RQD (Rock Quality Designation) This value (given as a percent) is the ratio of the total length of all core segments greater than 4 inches long (between natural fractures) to the core run. Disk fractures that develop as a result of loss of moisture, drilling, or handling are not counted. If the core is severely fractured, the corresponding RQD is low.

Fracture frequency The number of *natural fractures* per 10 feet (this does not include induced breaks along bedding). Experience shows that there is generally good correlation between RQD and fracture frequency (fig. 10).

Distance between horizontal separations is the length of core segments as they come out of the core barrel. This includes mechanically and handling-induced separations along bedding as well as natural fractures. Note that if the distance between horizontal separations is less than 0.2 feet, the accompanying RQD and fracture frequency may *not* reflect severely broken core because the separations occur along bedding planes during or after drilling.

Fractures Fractures are recorded as a simple sketch of core fractures (fig. 10), and may be compared with the packer test data recorded on the form shown in figure 7.

To provide general evaluation of the data, two summary sheets per test hole diagramatically show the recorded observations from the data forms. Figure 9 shows the drilling rates and rock discontinuity information, whereas figure 12 depicts the dip of mapped joints within a specific unit of core.

Glacial Drift: Field Procedures

Tables that summarize engineering data for drift samples are provided. Samples typically about 1.5 feet long were collected every 5 feet. These data include blow counts (N; number per foot), unconfined compressive strength (Qu; tons/ft^2) by pocket penetrometer, moisture content (W; percent). Selected samples were tested for dry and moist density. Also included for each sample are laboratory particle-size determinations by hydrometer, for gravel, sand, silt, and clay.

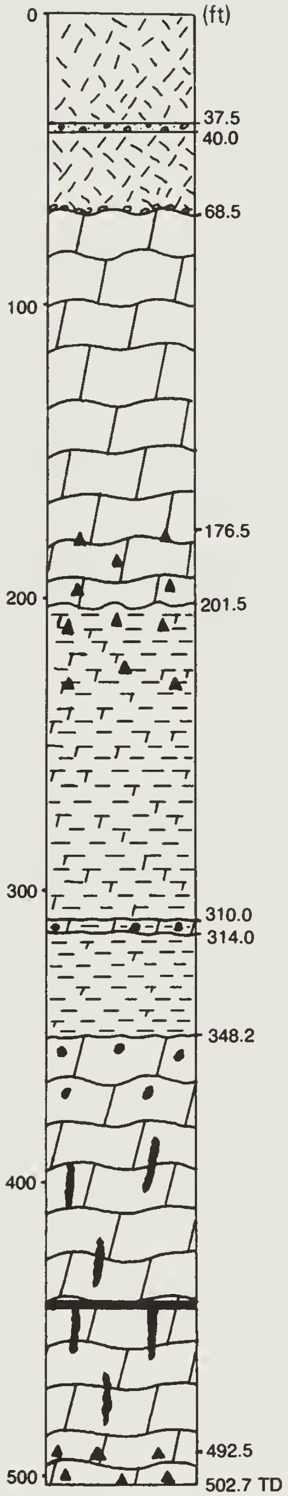
Blow counts are the number of impacts needed to drive a split-spoon sampler (outside diameter = 2.0 in.) 12 in. by a 140-pound hammer dropped 30 in. The samples have an outside diameter of about 1⅜ inch.

Unconfined compressive strength measurements were made with a Soiltest Model CL-700 pocket penetrometer. Measurements were taken on the ends and insides of sample cores; the given value is an average of at least two of these tests.

Moisture content is the ratio of the weight of water in the sample to the weight of the dry solids.

Both moist and dry density were determined sporadically depending on sample recovery and cohesiveness. Drift samples between 4.0 and 5.5 in. long were measured for length and diameter and stored in glass jars. The samples were weighed, dried, and then reweighed and remeasured.

Particle-size determinations were made in the laboratory by hydrometer analysis (ASTM 0-4-22, 1972). We define particle size classes as follows: *clay*, <0.0039 mm; *silt*, between 0.0625 and 0.0039 mm; *sand*, between 2.0 and 0.0625 mm; and *gravel*, >2.0 mm.



QUATERNARY SYSTEM

PLEISTOCENE SERIES

WEDRON FORMATION

YORKVILLE TILL MBR.

Till; olive-gray loam (0.0–37.5 ft)

Gravel (37.5–40.0 ft)

MALDEN TILL MBR.

Till; grey silty clay (40.0–68.5 ft)

SILURIAN SYSTEM

KANKAKEE AND JOLIET DOLOMITE (undifferentiated)

Dolomite, light olive gray, light greenish gray, and pinkish gray, very fine-grained, wavy beds separated by thin greenish gray shaly partings slightly vuggy in zones (68.5–176.5 ft)

ELWOOD DOLOMITE FORMATION

Dolomite, as above, but cherty (176.5–201.5 ft)

ORDOVICIAN SYSTEM

MAQUOKETA SHALE GROUP (undifferentiated)

Greenish gray dolomitic shale and shaly dolomite; pyritic; cherty in upper 30 feet (201.5–310.0 ft)

Dolomite, light olive gray, coarse-grained, fossiliferous, oil in vugs (310.0–314.0 ft)

Shale, olive gray, dolomitic, laminated (314.0–348.2 ft)

GALENA DOLOMITE GROUP

WISE LAKE DOLOMITE FORMATION

Dolomite, yellowish brown, fine- to medium-grained, vesicular and vuggy, in wavy beds separated by thin shaly partings; some pyrite in vugs; numerous clay-filled solution joints; bentonite bed at 348.2–492.5 ft and clay filled joint at 440.6–444.5 ft

DUNLEITH DOLOMITE FORMATION

Dolomite, as above, but cherty (492.5–502.7 ft)

Figure 12 Stratigraphic column for Test Hole F-1.

TEST HOLE ISGS F-1

Location: SW¼ NW¼ SW¼ SE¼ Sec. 20, T39N, R9E
Farm: Fermilab National Accelerator Laboratory
Surface elevation: 739 feet
Total depth: 503 feet

Stratigraphy

Bedrock

The stratigraphic column in figure 12 shows the lithologies and depths of the drift and rock units encountered in F-1. The hole penetrated to the top of the cherty Dunleith Dolomite Formation of the Galena Dolomite Group. The hole encountered (from top to bottom) 68.5 feet of drift; 108.2 feet of light gray, very fine-grained dolomite (Joliet-Kankakee Formations, undifferentiated); 24.8 feet of light gray, very fine-grained, cherty dolomite (Elwood Dolomite Formation), 146.7 feet of greenish gray and olive gray shale interbedded with light gray, fine- to medium-grained, fossiliferous, vuggy dolomite (Maquoketa Shale Group); 144.3 feet of yellowish brown, fine- to medium-grain, vuggy dolomite (Galena Dolomite Group, Wise Lake Formation); and 10.2 feet of yellowish brown dolomite with reddish-brown shaly partings (Galena Dolomite Group; Dunleith Dolomite Formation). Of particular interest are (1) the cherty dolomitic shales and shaly dolomite, which are not typical of the Maquoketa Group, (2) the thin dolomite grainstone (coarse-grained carbonates) from 310 to 314 feet, and (3) the K-bentonite bed and clay-filled joints encountered in the Wise Lake Formation of the Galena Group.

Glacial Drift

The glacial deposits encountered in boring F-1 consist of brownish gray tills and thin dolomitic gravel beds that belong to the Wedron Formation (fig. 12). The glacial drift at the Fermilab site is described in Landon and Kempton (1971) and Kemmis (1978). Detailed regional correlations are in progress.

Geophysical Logging

The geophysical logs run in Test Hole F-1 include caliper, spontaneous potential, single-point resistivity, natural gamma radiation, neutron, and density logs. Figure 13 shows the gamma-ray and neutron logs for F-1. The remaining logs are available on open file at the ISGS.

■ Natural Gamma-Ray and Neutron Logs

Natural gamma and neutron logs are graphed simultaneously on the left and right sides of figure 13, respectively. The natural-gamma log has distinctive levels of radiation throughout most of the formation boundaries. A prominent reentrant is present between 440.6 to 444.5 feet within a bentonite bed and clay filled joint. (Bentonite beds in this unit are typically only 0.1 to 0.2 feet thick.) The neutron log is used chiefly for measurement of moisture above the water table and total porosity below the water table. According to the log, the top of the zone of saturation is considered to be in the range of 4–10 feet below ground level. The neutron log shifts dramatically to the right at 65 feet as the sonde encountered air above the water in the borehole; therefore, porosity measurements above or below this level must be adjusted.

The zones with greatest porosity shown on the neutron log occur in the Maquoketa Group between 202–348 feet. Zones of porosity in the glacial drift occur between depths of 5–25 and 28–65 feet.

Hydrogeologic Data

■ Pressure Testing

The individual packer test results for this boring are listed in table 7, and the range of hydraulic conductivity values for these intervals is shown in figure 13.

The packer assembly was lowered to nearly the bottom of the borehole, and the packers were inflated to the predetermined pressure of 355 psi. The packer pressure would not hold at 355 psi but would hold at 180 psi (which is the hydrostatic pressure for this depth); this indicated a leak in a packer. The packer assembly was removed from the hole, the upper ruptured bladder replaced, and the assembly was placed back in the hole. It was suspected that the cause of the failure of the bladder might be related to the condition of the rock opposite the bladder so the assembly was placed a few feet higher in the hole with the bottom packer at a depth of 495 feet, and testing proceeded at 21-foot intervals up the hole with no other significant mechanical problems.

The uppermost test interval was from 75 to 96 feet; the casing extended to 80 feet, and the top of the rock was at 68.5 feet. Thus, these five tests are a combined measure of the permeability of the rock between 96 and 80 feet and the seal between the rock and the bottom of the casing. The computations were made as if the entire interval were rock, and the indicated rate of flow were moderate. The source of water for these tests was the nearby groundwater monitoring well; and as the test proceeded, the well water became cloudy, which suggests some movement of washed material from joints in the rock between the test boring and the well. No procedure was performed to test this theory.

Geotechnical Data

Bedrock

The results of the collection of fracture and rock discontinuity information are shown in figures 13 to 17. Figure 13 and table 8 show the drilling rates to be relatively steady at 1 to 3 minutes per foot. The core recovery and RQD were excellent (tables 9 and 10, respectively) and an increase in fracture frequency is limited to three zones (200 to 223, 323 to 358, and 417 to 421 feet). The diagram of the number and angle of dip of fractures in the Silurian core illustrates that most are nearly vertical with the exception of a few new horizontal separations (fig. 14). Core fractures in the Maquoketa section are oriented in equal numbers and at all different angles (fig. 15) because of a zone of soft sediment deformation features from 320 to 358 feet. When these fractures are not included in the dip diagram, the Maquoketa has fractures dipping near vertical (fig. 16). Fractures in the Galena Group show similar dips from 50° to 90° (fig. 17).

Drift

Engineering properties of the glacial drift at the Fermilab National Accelerator Laboratory Site were studied during construction of the present facilities. Landon and Kempton (1971) describe the properties of the drift units A through E (table 11); each unit has very consistent textures and engineering properties. The engineering properties of uppermost silty-clay till unit (Unit B) are also documented by Kemmis (1978).

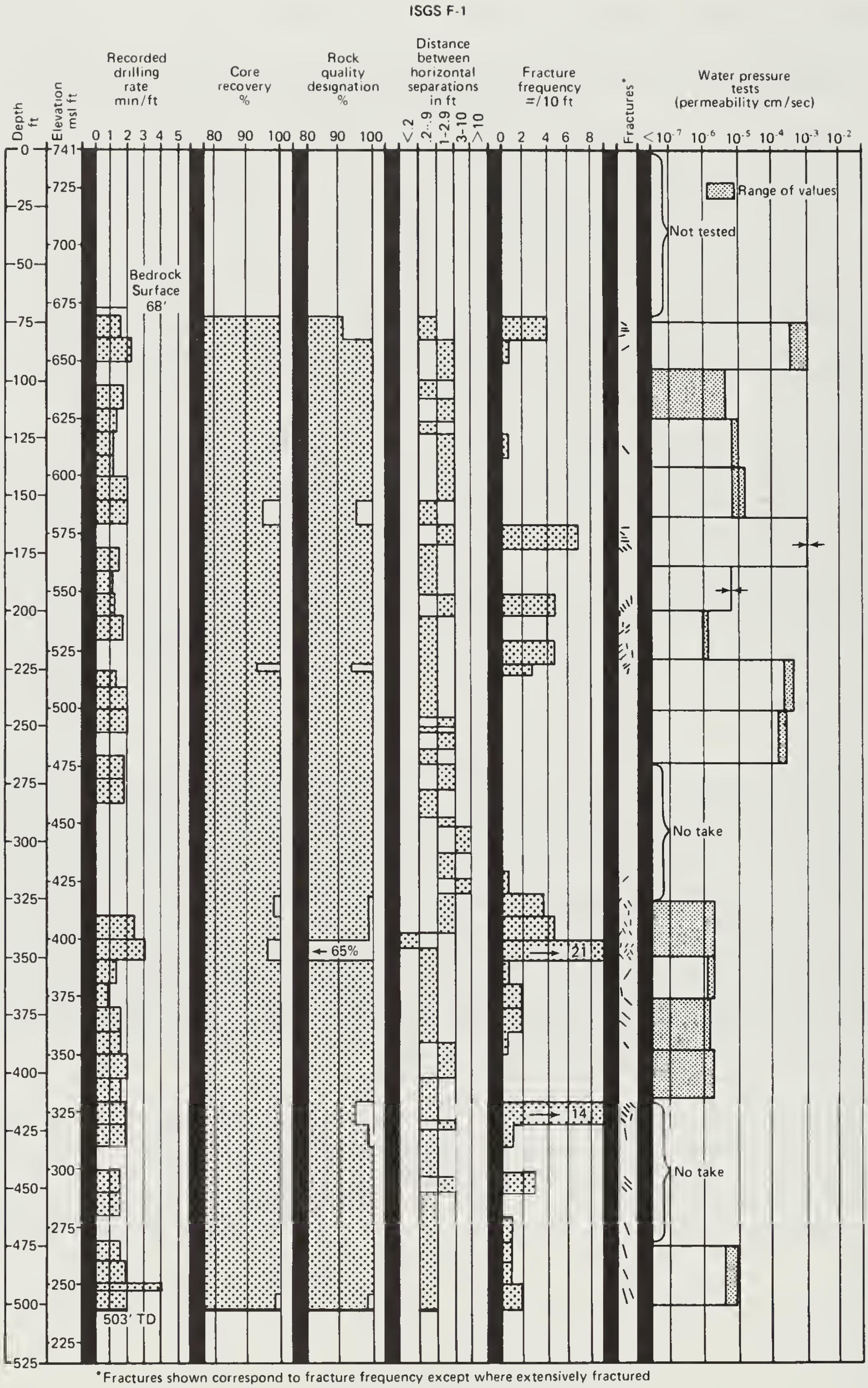
Table 7. Hydraulic conductivity (cm/sec) for Test Hole ISGS F-1 *

Test intervals (ft)	P_1	P_2	P_3	P_2	P_1
495-474	$8.0x10^{-6}$	$8.3x10^{-6}$	$7.5x10^{-6}$	$8.6x10^{-6}$	$1.1x10^{-5}$
474-453	0	0	0	0	0
453-432	0	0	0	0	0
432-411	0	0	0	0	0
411-390	0	$1x10^{-6}$	$2.5x10^{-6}$	$1x10^{-6}$	0
390-369	0	$5x10^{-7}$	$1.7x10^{-6}$	$5x10^{-7}$	0
369-348	$1.6x10^{-6}$	$2.2x10^{-6}$	$1.7x10^{-6}$	$2.2x10^{-6}$	$1.6x10^{-6}$
348-327	0	0	$1.7x10^{-6}$	$1x10^{-6}$**	0
327-306	0	0	$4.2x10^{-6}$	0	0
306-285	0	0	0	0	0
285-264	0	0	0	0	0
264-243	$3.4x10^{-4}$	$3.6x10^{-4}$	$2.9x10^{-4}$	$3.4x10^{-4}$	$3.2x10^{-4}$
243-222	$4.8x10^{-4}$	$4.2x10^{-4}$	$3.6x10^{-4}$	$4.4x10^{-4}$	$4.0x10^{-4}$
222-201	$9.4x10^{-5}$	$8.5x10^{-5}$	$9.8x10^{-5}$	$8.1x10^{-5}$	$9.9x10^{-5}$
201-180	$1.4x10^{-5}$	$1.4x10^{-5}$	$1.4x10^{-5}$	$1.4x10^{-5}$	$1.4x10^{-5}$
180-159	$9.2x10^{-4}$	$9.7x10^{-4}$	$8.8x10^{-4}$	$1.1x10^{-3}$	$1.3x10^{-3}$
159-138	$7.5x10^{-6}$	$8.7x10^{-6}$	$1.1x10^{-5}$	$8.7x10^{-6}$	$7.5x10^{-6}$
138-117	$1.6x10^{-4}$	$1.4x10^{-4}$	$1.3x10^{-4}$	$1.3x10^{-4}$	$1.2x10^{-4}$
117-96	0	$3.5x10^{-6}$	$4.0x10^{-6}$	$3.5x10^{-6}$	0
96-75	$8.3x10^{-4}$	$1x10^{-3}$	$8.9x10^{-4}$	$8.6x10^{-4}$	$8.5x10^{-4}$

*Below a depth of 159 feet, P_1 = 35 psi,
P_2 = 70 psi,
P_3 = 100 psi

Above a depth of 159 feet, P_1 = 10 psi,
P_2 = 30 psi,
P_3 = 50 psi

**Reverse flow



*Fractures shown correspond to fracture frequency except where extensively fractured

Figure 13 Summary diagram for Test Hole F-1.

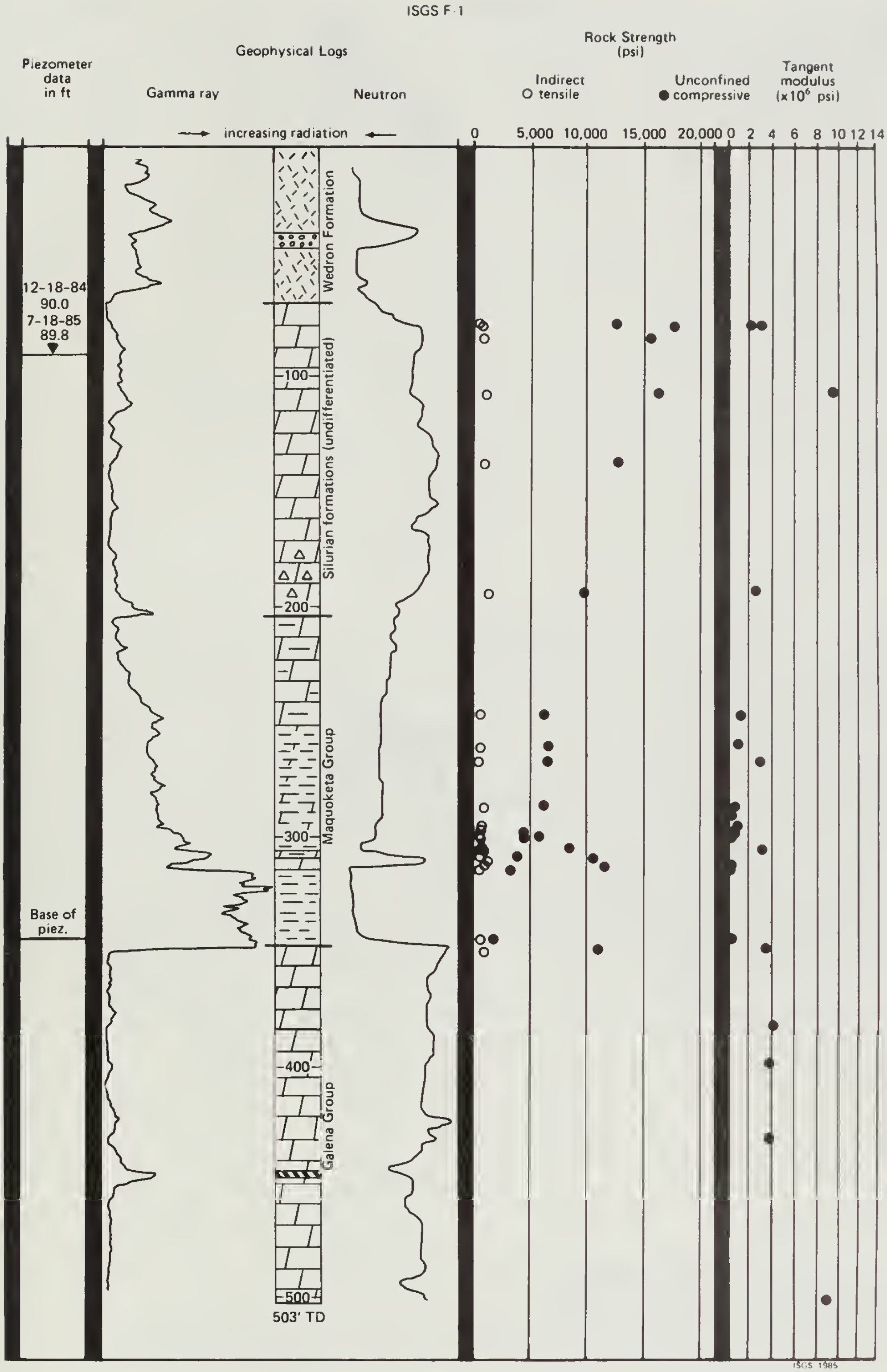


Figure 13 *continued.*

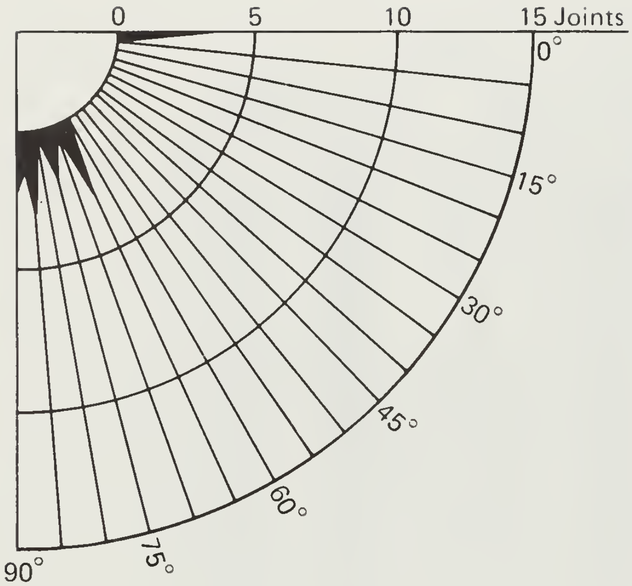


Figure 14

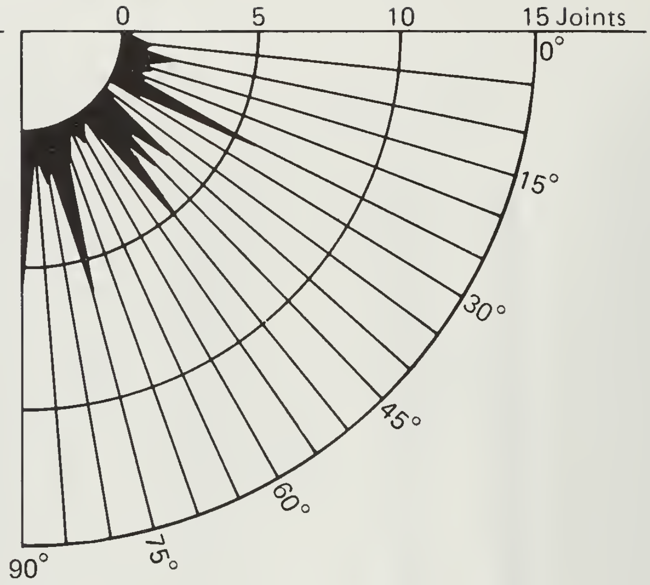


Figure 15

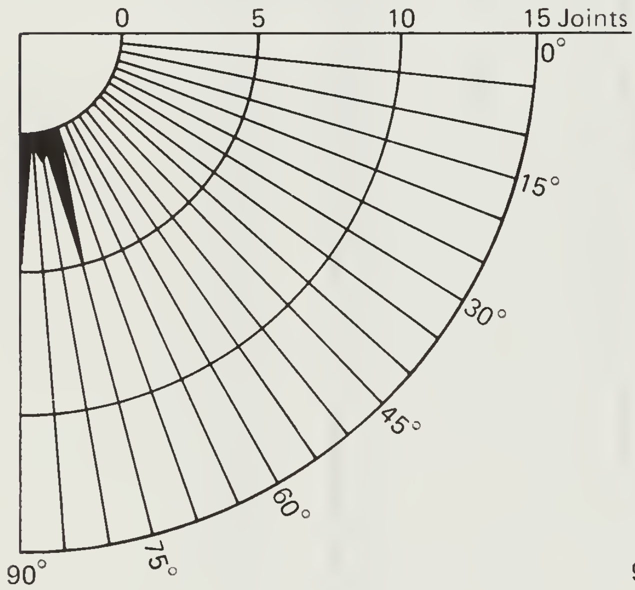


Figure 16

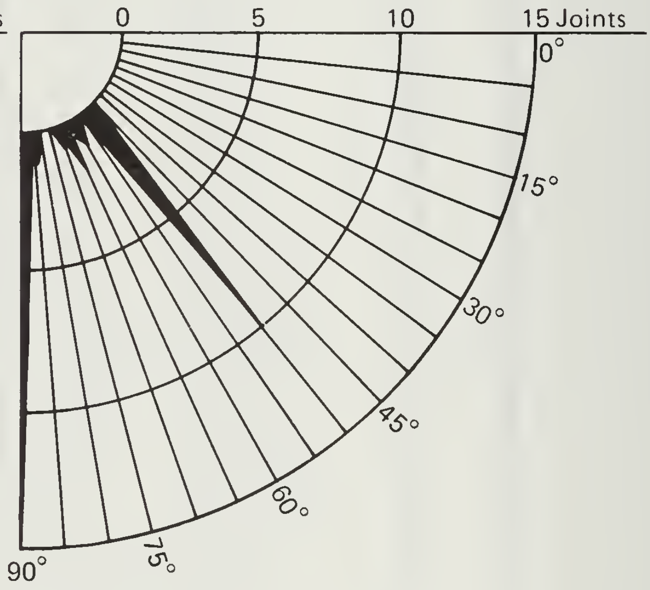


Figure 17

Dip diagrams of joints in Test Hole F-1:
14 130 feet of cored Silurian System strata.
15 147 feet of cored Maquoketa Group strata (soft sediment features *included*).
16 147 feet of cored Maquoketa Group strata (soft sediment features *excluded*).
17 154 feet of cored Galena Group strata.

Table 8. Mean drilling rates per hole and stratigraphic unit (min/ft)

Borehole no.	No. of core runs	Silurian	No. of core runs	Maquoketa	No. of core runs	Galena Wise Lake	No. of core runs	Galena Dunleith	No. of core runs	Platteville
F-1	11	1.68	8	2.07	12	1.75	1	3.00		
F-2	3	1.80	16	1.58	3	1.82				
F-3			7	2.31	9	1.52				
F-4	2	1.52	21	1.86	2	1.64				
F-5			5	2.04	12	1.80	4	1.86	2	2.61
F-6	6	1.80	16	2.04	3	2.33				
F-7	2	2.29	11	2.21	12	1.64	3	1.56		
F-9			6	2.97	13	2.25	4	1.95	5	2.44
Number of core runs	24		90		66		12		7	
Mean drill rates		1.76		2.02		1.83		1.91		2.49

Table 9. Summary of mean core recovery per hole and stratigraphic unit (%)

Borehole no.	No. of core runs	Silurian	No. of core runs	Maquoketa	No. of core runs	Galena Wise Lake	No. of core runs	Galena Dunleith	No. of core runs	Platteville
F-1	14	99.66	16	99.26	14	99.93	1	99.00		
F-2	2	99.90	23	99.80	6	99.90				
F-3			12	99.40	9	99.80				
F-4	2	100.00	21	99.40	2	100.00				
F-5			6	99.91	14	100.00	6	100.00	2	98.00
F-6	7	99.60	15	98.60	3	100.00				
F-7	2	100.00	13	99.65	14	100.00	3	99.33		
F-8			18	97.10	14	99.90				
F-9			8	98.91	15	100.00	5	99.60	5	99.80
Mean recovery per stratigraphic unit		99.71		99.07		99.95		99.67		99.29

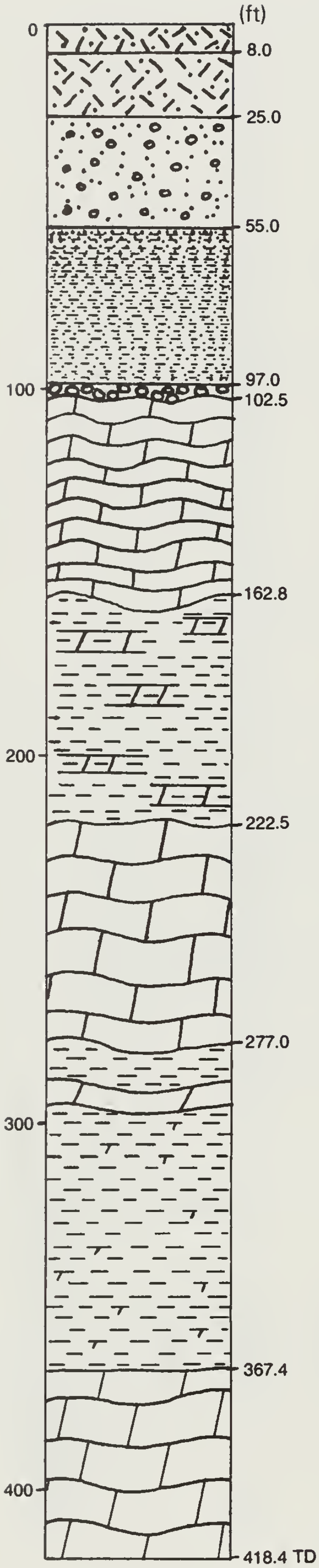
Table 10. Summary of mean rock quality designation (RQD) per hole and stratigraphic unit (%)

Borehole no.	No. of core runs	Silurian	No. of core runs	Maquoketa	No. of core runs	Galena Wise Lake	No. of core runs	Galena Dunleith	No. of core runs	Platteville
F-1	14	97.96	16	97.33	14	99.57	1	99.00		
F-2	6	99.90	21	96.50	5	99.90				
F-3			10	99.30	9	99.80				
F-4	2	100.00	21	98.70	2	100.00				
F-5			6	97.25	14	99.85	6	99.00	2	98.00
F-6	7	98.70	16	97.90	3	99.30				
F-7	2	100.00	13	99.65	14	99.42	3	97.00		
F-8			19	98.00	14	98.80				
F-9			8	97.40	15	99.60	5	94.60	5	99.80
Mean RQD per stratigraphic unit		98.77		97.97		99.52		97.13		99.29

Table 11. Engineeering properties of drift for Test Hole ISGS F-1

Depth of sample (ft)	Unit description	N (blows per ft)	qp+ (tons/ft^2)	Moisture content (%)	Dry density (gm/cm^3)	Moist density (gm/cm^3)	Grain Size Gvl** (%)	Sand* (%)	Silt* (%)	Clay* (%)	Unified soil classification
8.5-10	olive gray, gravelly loam till	18	4.0	10.8	---	---	3.7	43.0	46.3	10.7	CL
18.5-20		9	1.7	---	---	---	10.0	24.1	45.4	30.6	CL
28.5-30		15	3.7	---	---	---	14.4	36.9	39.6	23.5	CL
38.5-40	gravel	34	---	---	---	---	---	---	---	---	GP
48.5-60		30	<----------NO SAMPLE---------->								
58.5-60	brownish gray gravel-bearing silty clay till	15	<----------NO SAMPLE---------->								
60.5-62		--	2.5	---	---	---	34.5	11.0	41.3	47.7	CL
68.5	gravel	--	<----------NO SAMPLE---------->								GP
	bedrock										

*percentage of < 2-mm fraction
**percentage of whole sample
+as measured by a pocket penetrometer



QUATERNARY SYSTEM
PLEISTOCENE SERIES
WEDRON FORMATION
WADSWORTH TILL MEMBER
Till; orange sandy loam (0.0–8.0 ft)

HAEGER TILL MEMBER
Till; orange to gray sandy loam (8.0–25.0 ft) and sand and gravel (25.0–55.0 ft)

YORKVILLE TILL MEMBER
Silt and fine sand; gray, laminated (55.0–97.0 ft)

Gravel (97.0–102.5 ft)

SILURIAN SYSTEM
KANKAKEE DOLOMITE FORMATION
Dolomite, light olive gray, greenish gray, and pinkish gray, fine-grained, wavy beds separated by olive-gray and greenish gray shaly partings (102.5–162.8 ft)

ORDOVICIAN SYSTEM
MAQUOKETA SHALE GROUP
BRAINARD SHALE
Shale, greenish gray, some purple and reddish gray shales, very silty; some minor irregularly bedded, fossiliferous, medium-grained dolomite (162.8–222.5 ft)

FORT ATKINSON DOLOMITE
Dolomite, light olive gray, medium grained with thin olive-gray shaly partings (222.5–277.0 ft)

SCALES SHALE
Shale, olive gray, silty, with minor olive gray, fine-grained dolomite beds; greenish gray shale at Galena contact (277.0–367.4 ft)

GALENA DOLOMITE GROUP
WISE LAKE DOLOMITE FORMATION
Dolomite, pale yellowish brown, medium-grained, wavy beds separated by thin reddish gray to olive gray shale partings; some pyritic zones, vuggy and vesicular with some oil in vugs (367.4–418.4 ft)

Figure 18 Stratigraphic column for Test Hole F-2.

TEST HOLE ISGS F-2

Location: NE¼ NE¼ NE¼ SE¼ Section 17, T40N, R9E
Farm: Pratts Wayne Woods Forest Preserve; Forest Preserve District of Du Page County
Surface elevation: 785 feet
Total depth: 418 feet

Stratigraphy

Bedrock

The stratigraphic column (fig. 18) shows the lithologies and depths of the drift and rock units encountered in F-2. The hole penetrated the Wise Lake Dolomite Formation to a total depth of 418.4 feet. The hole penetrated (from top to bottom) 102.5 feet of drift; 60.3 feet of light gray, very fine-grained dolomite (Silurian Kankakee Dolomite Formation); 204.6 feet of greenish gray and olive-gray shale interbedded with fine- to medium-grained argillaceous dolomite (Maquoketa Shale Group); and 51.0 feet of yellow-brown medium-grained, vuggy dolomite (Galena Dolomite Group, Wise Lake Dolomite Formation). Of note within the Maquoketa Group are (1) the purple and red shale in the Brainard Formation at the top of the Maquoketa, and (2) a relatively thick Fort Atkinson Dolomite (54.5 feet) in the middle of the section.

Glacial Drift

Borehole F-2 penetrates 102.5 feet of the Wedron Formation. Materials encountered from top to bottom includes 8.0 feet of orange loamy till (Wadsworth Till Member); 17.0 feet of orange to gray sandy loam till (Haeger Till Member); 30.0 feet of gray sand and gravel (outwash, Haeger Till Member); and 42.0 feet of interbedded gray silt and fine sand (lacustrine), including a basal 5.5 foot thick gravel (Yorkville Till Member?).

Geophysical Logging

A complete suite of logs was run on this hole. The gamma-ray and neutron logs are shown in figure 19. The remaining logs are available on open file at the ISGS.

Hydrogeologic Data

- **Pressure Testing**

The results of the individual pressure test intervals for this boring are listed in table 12; the hydraulic conductivity values for test intervals range from 4×10^{-7} to 1×10^{-4} cm/sec. (fig. 19).

Geotechnical Data

Bedrock

Borehole F-2 is similar to F-1 with a loss of circulation in the jointed Silurian rocks (figs. 19 and 20) and also a concentration of fractures in the lower 26 feet of Maquoketa immediately above the contact with the Galena (figs. 19 and 20). This fractured zone (58 fractures in 26 feet) seems to be a soft sediment deformation feature with slips oriented in multiple directions (fig. 21). Figure 22 shows the dip of the fractures with soft sediment deformation excluded.

Core recovery was excellent throughout the entire hole; the lowest value was 98 percent (table 9). The rock quality designation (RQD) values were excellent (table 10) except for the fractured zone in the Maquoketa directly above the Galena. Here an RQD value was 64 percent, indicating that rock quality was only fair (fig. 19).

Drift

The drift at F-2 is subdivided from top to bottom: sandy loam till with medium bearing capacity (0 to 25 feet); stratified sand, and sand and gravel with low bearing capacity (25 to 55 feet); and finally, stratified clayey silt with low bearing capacity (55 to 97 feet). The engineering properties for this hole are shown in table 13.

Table 12. Hydraulic conductivity (cm/sec) for Test Hole ISGS F-2 *

Test intervals (ft)	P_1	P_2	P_3	P_2	P_1
401-380	0	0	4.4×10^{-7}	0	0
380-359	1.9×10^{-6}	1.1×10^{-6}	9×10^{-7}	1.1×10^{-6}	1.9×10^{-6}
261-240	0	5.7×10^{-6}	8.7×10^{-6}	inconclusive**	0
240-219	2.7×10^{-5}	2.3×10^{-5}	2.5×10^{-5}	2.4×10^{-5}	2.7×10^{-5}
198-177	0	0	6.1×10^{-6}	0	0
177-156	0	0	1.4×10^{-5}	0	0
156-135	1.0×10^{-5}	1.5×10^{-4}	1.5×10^{-4}	7.6×10^{-5}**	7.2×10^{-5}**
135-114	1.4×10^{-6}	1.0×10^{-6}	6.1×10^{-5}	0	1.4×10^{-6}

* Below a depth of 156 feet, P_1 = 30 psi,
P_2 = 70 psi,
P_3 = 100 psi

Above a depth of 156 feet, P_1 = 10 psi,
P_2 = 30 psi,
P_3 = 50 psi

**Reverse flow

Table 13. Engineering properties of drift for Test Hole ISGS F-2

Depth of sample (ft)	Unit description	N (blows per ft)	qp+ (tons/ft^2)	Moisture content (%)	Dry density (gm/cm^3)	Moist density (gm/cm^3)	Grain Size Gvl** (%)	Grain Size Sand* (%)	Grain Size Silt* (%)	Grain Size Clay* (%)	Unified soil classification
3.5-5	orange to	16	---	---	---	---	---	---	---	---	CL
8.5-10	sandy loam till	52	1.25	9.6	---	---	22.2	46.5	39.7	13.8	CL
13.5-15	orange to	64	1.50	---	---	---	24.5	51.8	36.4	11.8	CL
18.5-20	gray sandy	72	2.60	9.0	---	---	28.7	50.9	38.0	11.1	CL
23.5-25	loam till	48	4.00	10.1	---	---	25.1	51.0	37.0	12.0	CL
28.5-30	gray	36	---	---	---	---	71.1	70.8	18.3	10.9	GW
33.5-35	sand and	22	---	9.9	---	---	14.4	90.5	4.6	4.9	SP
38.5-40	gravel	28	---	9.4	---	---	---	---	---	---	SP
43.5-45		36	---	12.2	---	---	0.1	91.8	5.8	2.4	SP
48.5-50		46	---	10.1	---	---	---	---	---	---	SP
53.5-55		44	---	9.2	---	---	---	---	---	---	SP
58.5-60	interbedded, laminated,	34	---	8.4	---	---	2.8	92.2	4.8	3.0	SP
63.5-65	gray silt,	26	2.20	---	---	---	---	---	---	---	SM
68.5-70	fine sand	40	<0.5	---	---	---	2.6	24.0	49.5	26.5	CL
73.5-75		24	<0.5	---	---	---	2.0	17.1	62.7	20.2	CL
78.5-80		38	<0.5	---	---	---	4.9	26.9	57.4	15.7	CL
83.5-85		22	0.25	---	---	---	0.0	40.2	52.0	7.8	SM
88.5-90		44	<0.5	---	---	---	---	---	---	---	SP
93.5-95		34	<0.5	---	---	---	0.0	93.0	3.0	4.0	SP
	gray gravel	54	---	---	---	---	65.0	77.0	13.6	9.4	GP
	bedrock										

*percentage of < 2 mm fraction
**percentage of whole sample
+as measured by pocket penetrometer

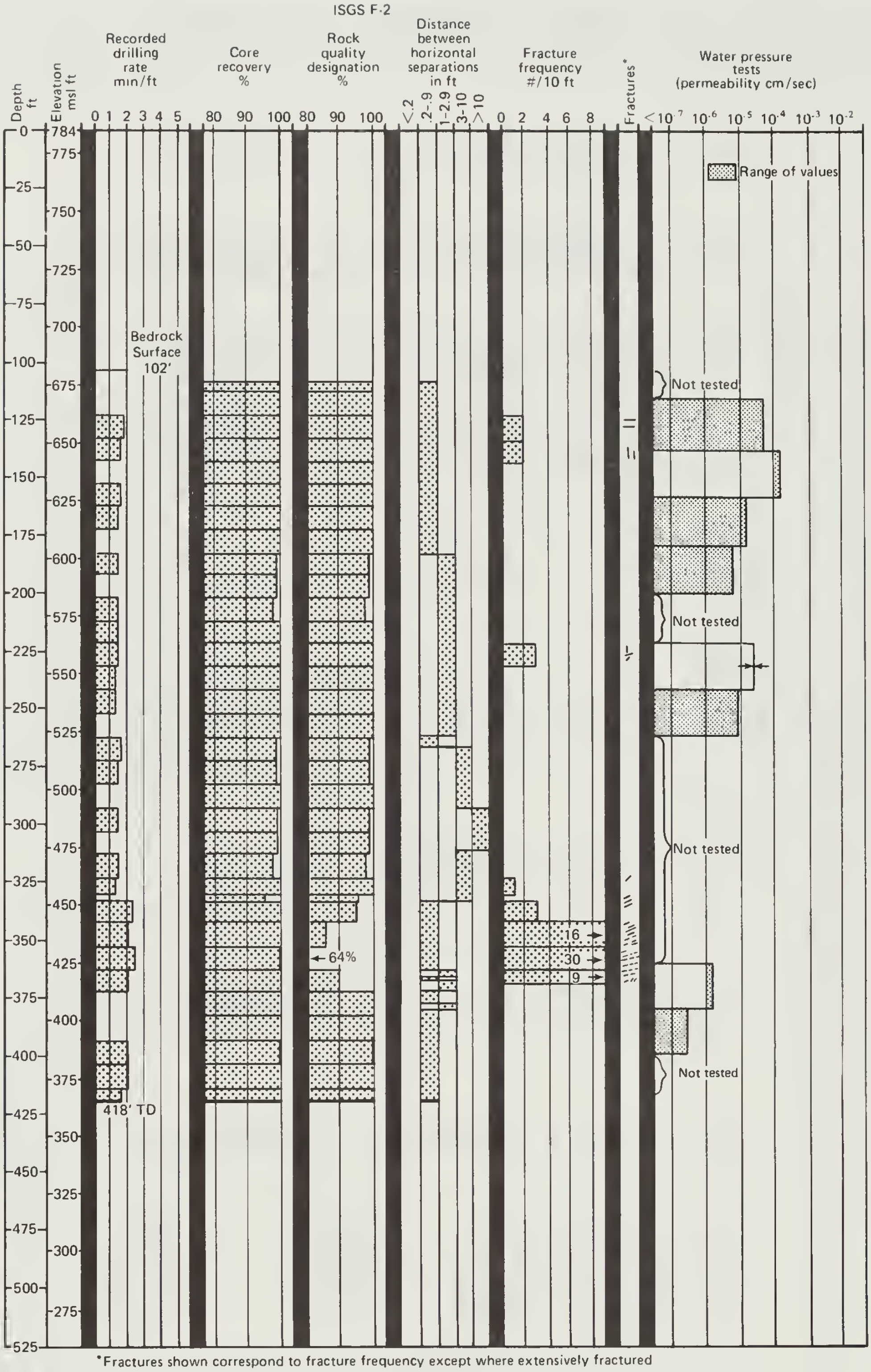


Figure 19 Summary diagram for Test Hole F-2.

Figure 19 *continued.*

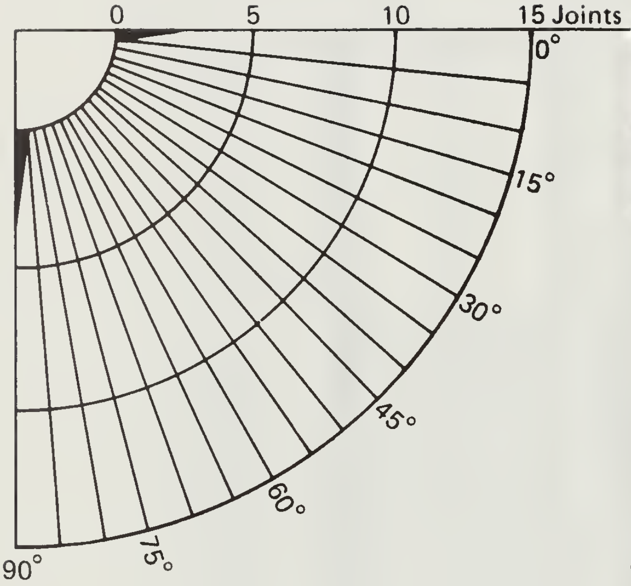


Figure 20

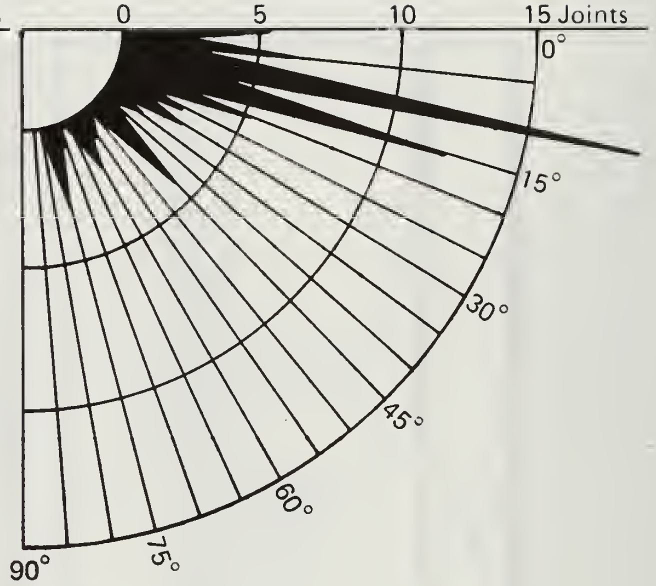


Figure 21

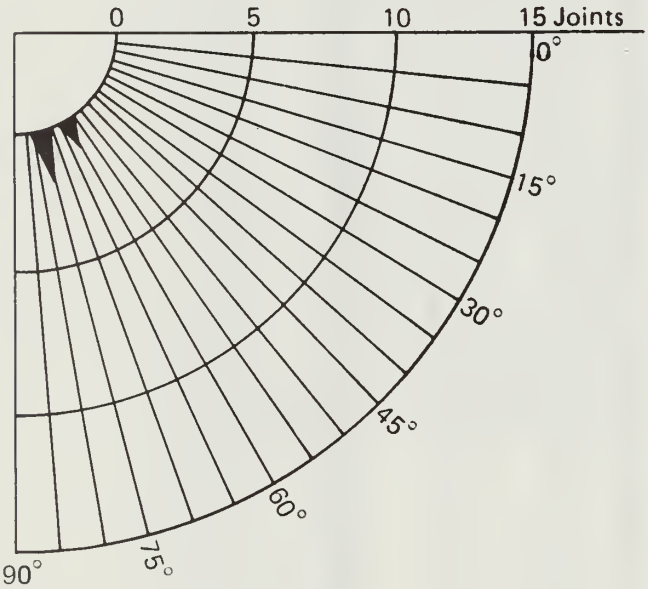


Figure 22

Dip diagrams of joints in Test Hole F-2:
20 54 feet of cored Silurian System strata.
21 204 feet of cored Maquoketa Group (soft sediment deformation features *included*).
22 204 feet of cored Maquoketa Group (soft sediment deformation features *excluded*).

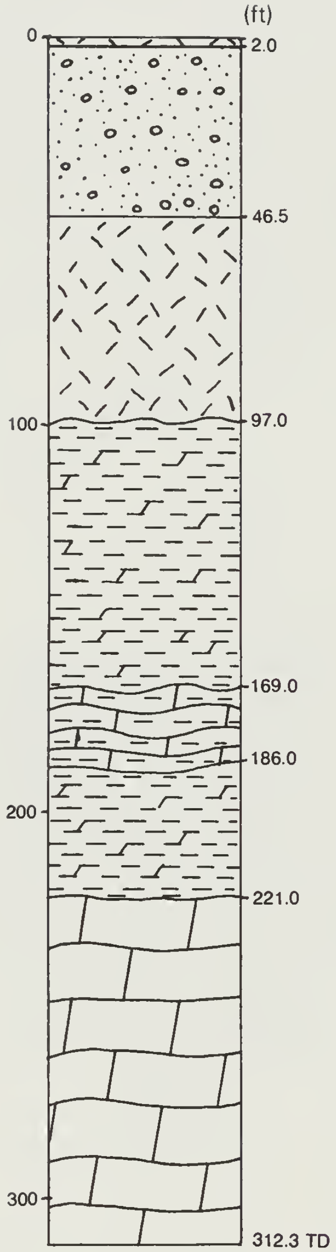


Figure 23 Stratigraphic column for Test Hole F-3.

TEST HOLE ISGS F-3

Location: SE¼ NW¼ SE¼ SW¼ Section 2, T40N, R8E
Farm: Blackhawk Forest Preserve; Forest Preserve Commission, Kane County
Surface elevation: 702 feet
Total depth: 312 feet

Stratigraphy

Bedrock

The stratigraphic column (fig. 23) shows the lithologies and depths of the drift and bedrock units encountered in F-3. The hole penetrated the Wise Lake Dolomite Formation of the Galena Group to a total depth of 312.3 feet. The units encountered (from top to bottom) are 97 feet of drift; 124 feet of olive-gray and greenish gray shale interbedded with light gray to olive gray, fine- to coarse-grained, argillaceous, vuggy dolomite (Maquoketa Shale Group); and 91.3 feet of yellow-brown fine- to medium-grained, vuggy dolomite (Galena Dolomite Group, Wise Lake Dolomite Formation).

Glacial Drift

Test Hole F-3 is located in a gravel pit where about 10 feet of material has been stripped. An adjacent gravel pit wall exposes in-place material above the test hole; 7.5 feet of clean sand and gravel capped by 1.5 feet of silt and fine sand were present. The boring penetrated 97 feet of drift. From top to bottom, the hole encountered 46.5 feet of pinkish brown gravel and sand (outwash, Henry Formation, MacKinaw Member (?)) and 50.5 feet of pinkish brown loamy till (Tiskilwa Till Member). There are several sandy seams up to 1.5 feet thick throughout the till and a 1.5 foot thick basal gravel.

F-3 is located near the axis of the "Newark" bedrock valley, a major bedrock valley with gentle sloped sides. Seismic data indicate that the center of the valley is located beneath or slightly east of the Fox River, about 500 feet east of F-3 (R. H. Gilkeson, personal communication).

Geophysical Logging

The gamma-ray and neutron logs are shown in figure 24. The temperature log was run 63 hours after test-boring completion, and thus, is probably representative of the groundwater regime. Borehole fluid temperatures ranged from 56° to 58°F, with warmer readings from the Galena Group below a depth of 226 feet.

Hydrogeologic Data

■ **Pressure Testing**

The results of the individual pressure tests for this boring are listed in table 14, and the range of hydraulic conductivity values for test intervals are shown graphically in figure 24.

Geotechnical Data

Bedrock

Relatively few fractures or joints were encountered in this borehole as compared to boreholes F-1 and F-2 (figs. 24, 25, and 26). All the joints or fractures encountered in the Maquoketa section were vertical and were present only in the thin (0.2 to 0.6 feet thick) dolomite layers; none were in the shaly sections (fig. 24). Joints are parallel to each other.

Bedrock topography maps and seismic data indicate the boring was drilled through the gently sloping valley wall of the buried "Newark" bedrock valley. The deepest part of the valley appears to be located about 500 feet east of the borehole and runs roughly north-south. The cross-valley relilef of the valley is about 100 feet; the hole is located about one-third of the way up the valley wall, which has a slope of approximately 5°. As material was eroded away from the valley, lateral support of the remaining material was also removed. The material that forms the valley walls slowly moved towards the center of the valley even after the drift fill was deposited (Ferguson, 1967). Soft, weak, shaly sections in the valley walls deformed and moved toward the center of the valley, producing tensile fractures in the dolomite. These fractures parallel the trend of the valley. We interpret the vertical joints found only in the dolomite layers in the upper 175 feet of borehole F-3 to be the result of this stress relaxation.

The core recovery and rock quality designation (RQD) for F-3 was excellent with all core runs having 100 or nearly 100 percent values (tables 9 and 10, respectively). Only one core run had the lower category of good for the RQD and core recovery (fig. 24). This core run encountered soft shaly seams at a depth of 135 to 140 feet.

Drift

The drift materials at F-3 (table 15) are subdivided from top to bottom: gravel and sand, presumably with high bearing capacity (0 to 47 feet); loam till with high bearing capacity (47 to 95 feet); and rock rubble from 95 to 97 feet. The "Newark" bedrock valley in this immediate area appears to be filled chiefly with loamy till.

Table 14. Hydraulic conductivity (cm/sec) for Test Hole ISGS F-3 *

Test intervals (ft)	P_1	P_2	P_3	P_2	P_1
309-288	2.5×10^{-6}	1.4×10^{-6}	4.1×10^{-6}	7×10^{-7}	0
288-267	2.5×10^{-6}	2.8×10^{-6}	2.0×10^{-6}	1.4×10^{-6}	2.5×10^{-6}
231-210	0	0	0	0	0
137-116	1.0×10^{-4}	1.1×10^{-4}	1.5×10^{-4}	9.6×10^{-5}	8.5×10^{-5}

* Below a depth of 150 feet, P_1 = 35 psi,
P_2 = 70 psi,
P_3 = 100 psi

Above a depth of 150 feet, P_1 = 10 psi,
P_2 = 30 psi,
P_3 = 50 psi

Table 15. Engineering properties of drift for Test Hole ISGS F-3

Depth of sample (ft)	Unit description	N (blows per ft)	qp+ (tons/ft^2)	Moisture content (%)	Dry density (gm/cm^3)	Moist density (gm/cm^3)	Grain Size: Gvl** (%)	Grain Size: Sand* (%)	Grain Size: #Silt* (%)	Grain Size: Clay* (%)	Unified soil classification
3.5-5	pinkish	<---NO SAMPLE--->									
	brown										
8.5-10	gravel	54	---	---	---	---	80.9	66.3	27.5	6.2	GP
13.5-15	and sand	100	---	---	---	---	67.3	79.6	14.8	5.6	GP
18.5-20		96	---	---	---	---	---	---	---	---	GP
23.5-25			---	---	---	---	---	---	---	---	BP
28.5-30		50	---	---	---	---	76.0	73.5	15.8	10.7	GP
33.5-35		66	---	---	---	---	69.5	78.2	16.7	5.1	GP
38.5-40		60	---	---	---	---	77.1	72.4	23.1	4.5	GP
43.5-45		---	---	---	---	---	---	---	---	---	GP
47.5-49			>4.5	9.6	---	---	3.4	25.0	40.5	34.5	CL
53.5-55	pinkish	<---NO SAMPLE--->									
	brown loam										
	till										
57.0-59	interbeds		>4.5	9.0	---	---	1.1	34.1	45.1	20.8	CL
63.5-65	of silt or		>4.5	10.1	---	---	0.0	34.1	58.2	7.7	CL
68.5-70	sand common		>4.5	9.9	---	---	9.4	27.2	38.3	34.5	CL
73.5-75			>4.5	---	---	---	4.4	28.8	45.6	25.6	CL
78.5-79.2			4.35/0.80	12.2	---	---	0.0	35.6	53.3	11.1	CL
83.5-85 A			>4.5	9.2	---	---	5.1	31.2	38.6	30.2	CL
83.5-85 B		---	---	---	---	---	13.8	27.0	39.8	33.2	CL
88.5-90 A			>4.5	10.1	---	---	4.4	27.2	41.1	31.7	CL
88.5-90 B		---	---	---	---	---	8.9	25.2	45.0	29.8	CL
93.5-95			>4.5	8.4	---	---	4.6	30.2	39.5	30.3	CL
95.5-98	gravel	---	---	---	---	---	---	---	---	---	GW
	bedrock										

*percentage of < 2 mm fraction
**percentage of whole sample
+as measured by pocket penetrometer

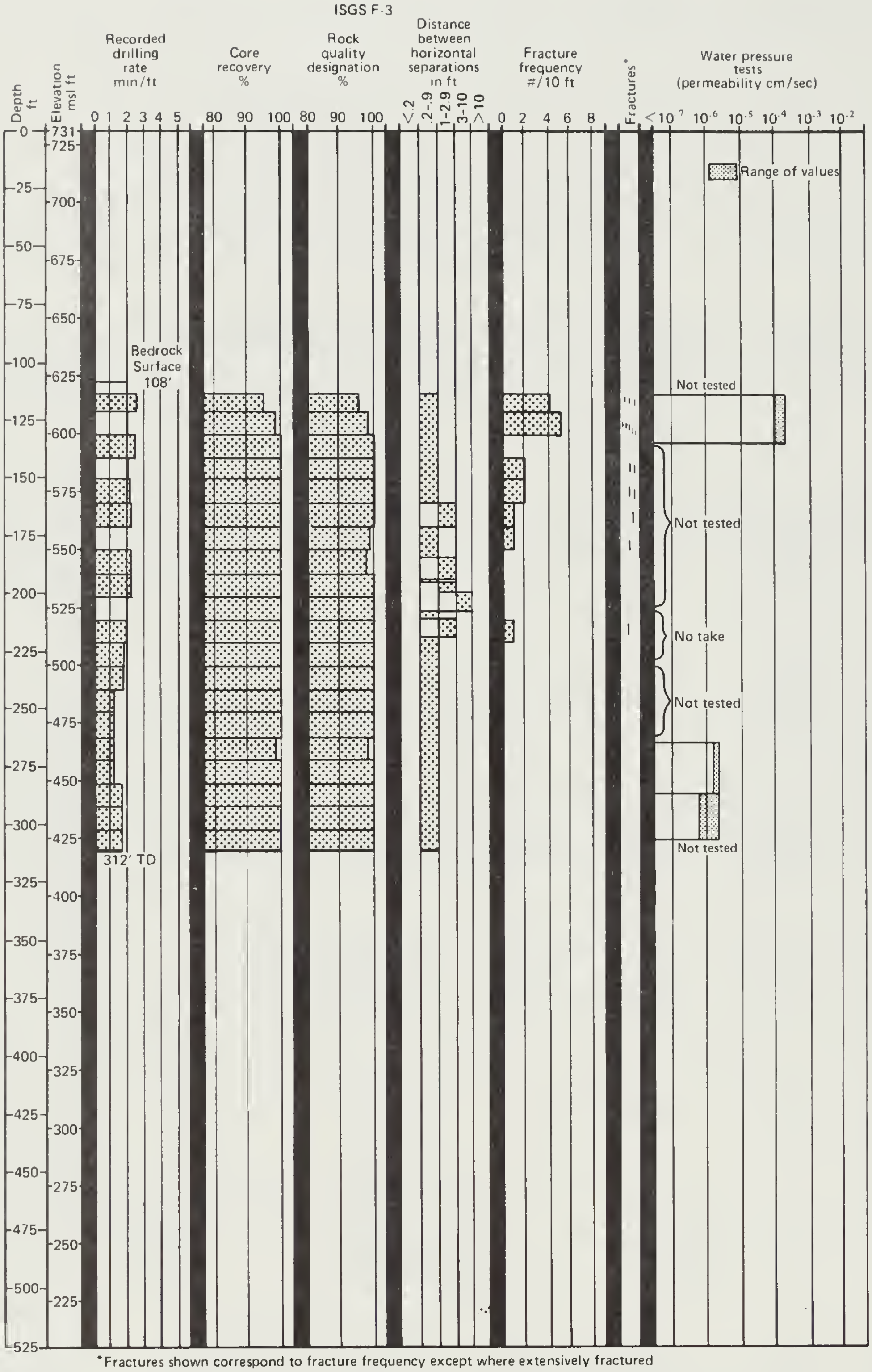


Figure 24 Summary diagram for Test Hole F-3.

Figure 24 *continued.*

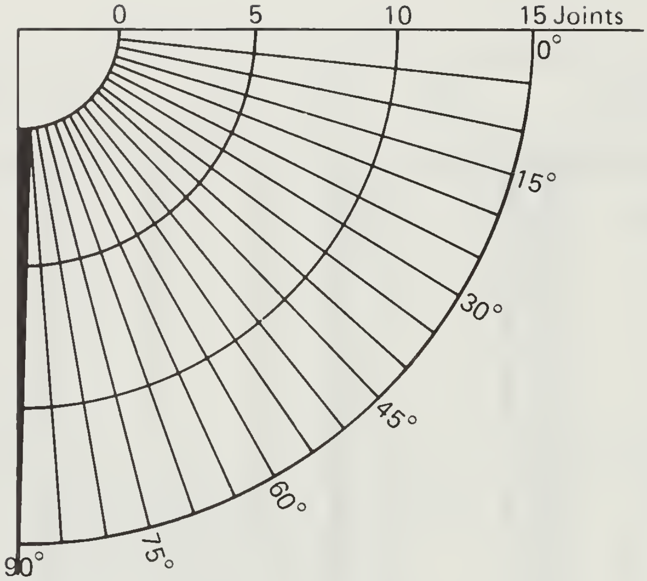


Figure 25

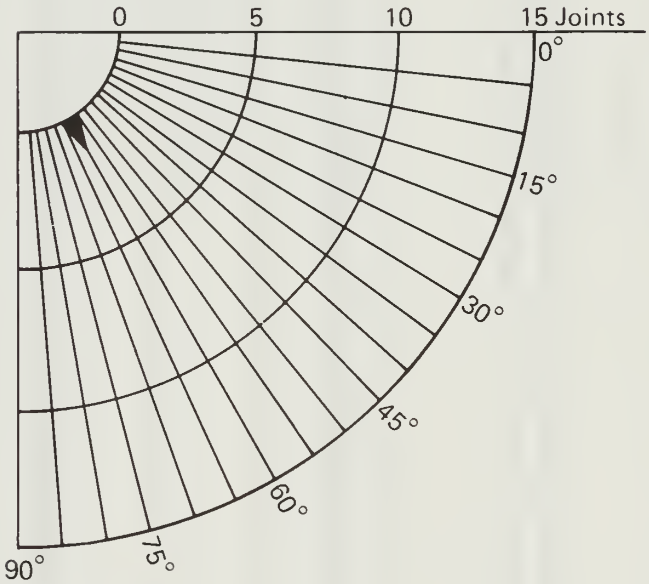
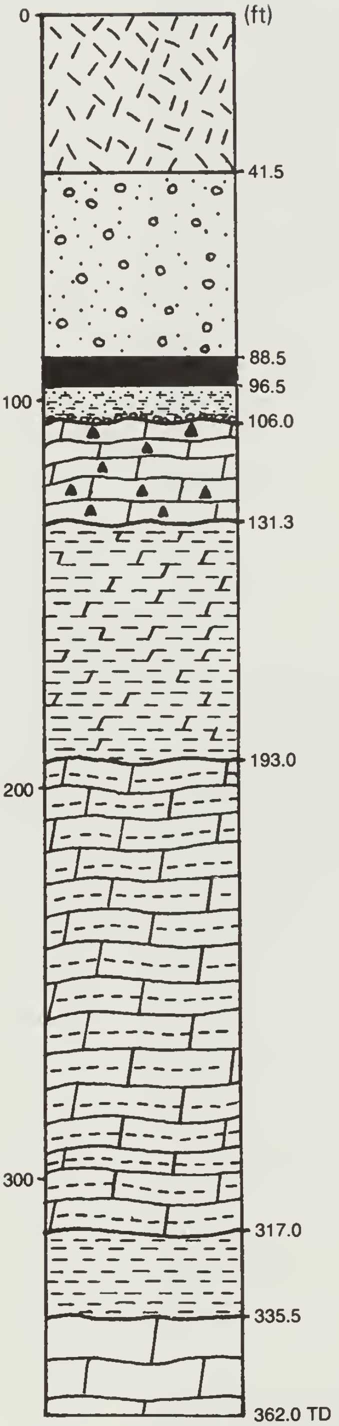


Figure 26

Dip diagrams of joints in Test Hole F-3:
25 118 feet of cored Galena Group strata.
26 92 feet of cored Galena Group strata.



QUATERNARY SYSTEM
PLEISTOCENE SERIES
WEDRON FORMATION
TISKILWA TILL MEMBER
Till; pinkish brown loam (0.0–41.5 ft); sandy gravel; pinkish, interbedded with gravelly silt and loam till (41.5–88.5 ft)

ROBEIN SILT
Black, organic-rich, silty loam (88.5–96.5 ft)

GLASFORD FORMATION
Loam; greenish grey, laminated (96.5–106.0 ft)

SILURIAN SYSTEM
ELWOOD DOLOMITE FORMATION
Dolomite, light olive gray to light greenish gray, fine-grained, very cherty; wavy beds separated by thin greenish gray shale partings (106.0–131.3 ft)

ORDOVICIAN SYSTEM
MAQUOKETA SHALE GROUP
Shale, greenish gray, silty, dolomitic, soft; minor dolomite beds, light olive gray, fine grained in irregular nodular beds, fossiliferous (131.3–193.0 ft)

Dolomite, light olive gray, mottled and speckled dark gray, fine- to coarse-grained, argillaceous, very fossiliferous (brachiopods and bryozoans), vuggy; wavy beds separated by thin olive gray shale partings (193.0–317.0 ft)

Shale, olive gray, dolomitic, fossiliferous, laminated (317.0–335.5 ft)

GALENA DOLOMITE GROUP
WISE LAKE DOLOMITE FORMATION
Dolomite, pale yellow brown, fine- to medium-grained, vuggy, pyritic; wavy beds separated by olive gray shaly partings (335.5–362.0 ft)

Figure 27 Stratigraphic column for Test Hole F-4.

TEST HOLE ISGS F-4

Location: SE¼ SW¼ NE¼ SE¼ Section 11, T41N, R6E
Farm: L. Lenschow Farm
Surface elevation: 912 feet
Total depth: 362 feet

Stratigraphy

Bedrock
The stratigraphic column (fig. 27) shows the lithologies and depths of the drift and bedrock units encountered in F-4. The hole penetrated into the Wise Lake Dolomite Formation of the Galena Dolomite Group to a total depth of 362 feet. The units encountered (from top to bottom) are 106 feet of drift; 25.3 feet of light gray, fine-grained, very cherty dolomite (Elwood Dolomite Formation); 204.2 feet of greenish gray to olive-gray shale interbedded with light gray coarse-grained, vuggy dolomite (Maquoketa Group); and 26.5 feet of yellow brown, fine- to medium-grained, vuggy dolomite (Galena Dolomite Group, Wise Lake Dolomite Formation). Of note is the particularly dolomitic Maquoketa section in the boring. More than 100 feet of the Maquoketa is coarse-grained fossiliferous dolomite.

From top to bottom, the units encountered include 41.5 feet of pinkish brown, gravel-bearing loamy till (Wedron Formation, Tiskilwa Till Member); 47.0 feet of coarse sandy gravel and medium-grained sand (Wedron Formation, Tiskilwa Till Member); 8.0 feet of organic-rich silty clay and diamicton (Robein Silt); and 9.5 feet of greenish gray laminated loam and silt loam till (lacustrine, Glasford Formation).

Geophysical Logging
The gamma-ray and neutron logs (fig. 28) indicate clean sand and gravel intervals between depths of 42 to 48 feet and 63 to 68 feet below land surface. The neutron configuration indicates the highest moisture content between 62 and 98 feet opposite sand and gravel. The lowest moisture content is opposite Silurian dolomite between 113 to 130 feet. The Maquoketa Shale Group extending from 131 to 335.5 feet, contains a large amount of coarse-grained vuggy dolomite. The most permeable of these layers extends from 222 to 239 feet.

Hydrogeologic Data

■ Pressure Testing
The results of the packer tests are in table 16; the hydraulic conductivity values for test intervals range from 9×10^{-7} to 1×10^{-3} cm/sec. (fig. 28). Borehole F-4 lost circulation during drilling at 291 feet in a vuggy zone in dolomite of the Maquoketa Group.

Geotechnical Data

Bedrock
The only highly fractured zone was encountered in the Maquoketa from 241 to 278 feet (figs. 28, 29, and 30). This fractured zone was not found in the lowest part of the Maquoketa as occurred in boreholes F-1 and F-2.

Core recovery was excellent throughout the entire hole with the lowest value of 95 percent in one core run (table 9). The rock quality designation (RQD) was also excellent with the lowest value of 91 percent being found in the fractured zone (table 10).

Drift

The drift at F-4 from top to bottom includes: (a) loamy till with high to very high bearing capacity (0–41.5 feet); (b) interbedded gravelly sand and sand with variable bearing capacity (41.5–88.5 feet); and (c) organic-rich or gleyed silty clay with very high to high bearing capacity (88.5–106.0 feet). The engineering properties of samples from this hole are shown in table 17.

Table 16. Hydraulic conductivity (cm/sec) for Test Hole ISGS F-4 *

Test interval (ft)	P_1	P_2	P_3	P_2	P_1
318-297	1.8×10^{-6}	0	8.9×10^{-7}	0	1.8×10^{-6}
297-276	2.3×10^{-3}	1.4×10^{-3}	5.2×10^{-4}	1.04×10^{-3}	1.05×10^{-3}

* P_1 = 35 psi,
P_2 = 70 psi,
P_3 = 100 psi

Table 17. Engineering properties of drift for Test Hole ISGS F-4

Depth of sample (ft)	Unit description	N (blows per ft)	qp+ (tons/ft^2)	Moisture content (%)	Dry density (gm/cm^3)	Moist density (gm/cm^3)	Grain Size: Gvl** (%)	Grain Size: Sand* (%)	Grain Size: Silt* (%)	Grain Size: Clay* (%)	Unified soil classification
3.5-5		28	---	10.9	---	---	5.4	36.8	36.6	26.6	CL
8.5-10		26	4.0	9.6	---	---	6.9	37.3	35.9	26.8	CL
			2.5 top	10.0							
13.5-15		54	>4.5	9.0	2.12	2.38	22.1	51.8	28.7	19.5	CL
				9.8							
18.5-20	pinkish	34	4.5	10.1	2.14	2.54	15.7	33.7	36.6	29.7	CL
	brown			10.1							
23.5-25	loam till	48	3.5	9.9	2.18	2.28	5.3	32.5	37.6	29.9	CL
				10.1							
28.5-30		36	3.0	9.3	---	---	7.9	37.1	35.8	27.1	CL
				9.4							
				10.1							
33.5-35		28	3.0	12.2	2.21	2.37	4.5	35.6	36.7	27.7	CL
38.5-40		32	---	10.1	2.19	2.35	8.0	34.0	38.0	28.0	CL
43.5-45	gravelly sand	74	---	10.8	---	---	---	---	---	---	SW

48.5-50	pinkish brown loam till	56	2.5	9.2	---	---	3.7	35.0	37.6	27.4	SW
				10.2							
53.5-55	pinkish	50	---	8.4	2.31	2.56	6.0	35.4	35.4	29.4	GP
58.5-60	sandy		---	---	---	---	47.2	79.7	15.1	5.2	GP
63.5-65	gravel and	68	---	---	---	---	40.4	75.0	17.1	7.9	GP
68.5-70	medium		---	---	---	---	0.3	89.9	8.8	1.3	SP
73.5-75	sand	60	---	---	---	---	54.6	79.7	13.7	6.6	GP
78.5-80			---	---	---	---	68.3	78.6	16.0	5.4	GP
83.5-85			---	---	---	---	2.4	88.9	7.4	3.7	GP
88.5-90	organic-rich,		4.5	39.5	---	---	---	---	---	---	OL
93.5-95	gray loam		>4.5	23.1	1.57	2.05	0.2	8.2	48.5	43.3	OL
98.5-100	(gleyed) silty clay	96	2.5	13.2	---	---	0.03	30.7	51.6	17.7	CL
	bedrock										

*percentage of < 2-mm fraction
**percentage of whole sample
+as measured by pocket penetrometer

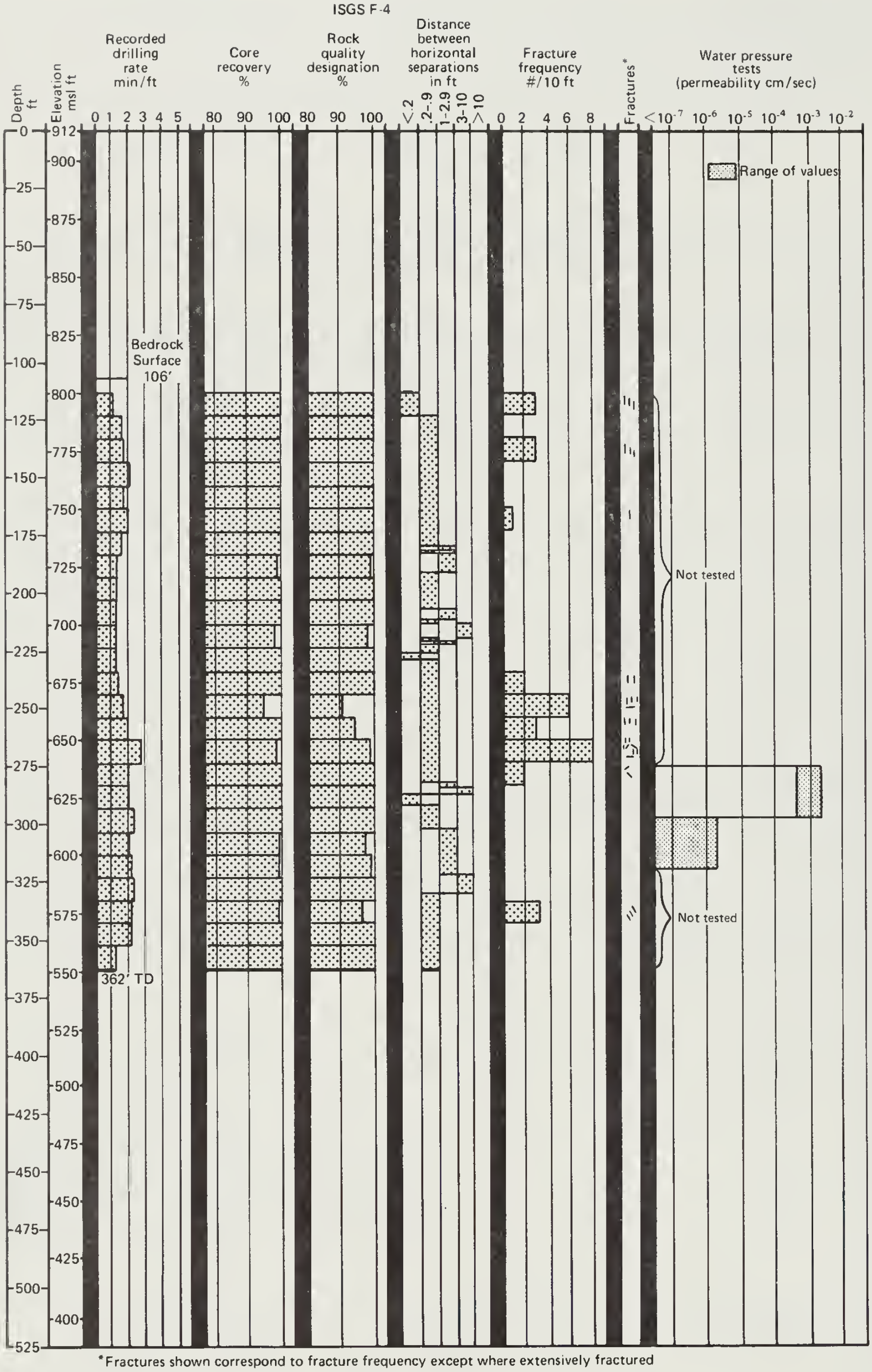


Figure 28 Summary diagram for Test Hole F-4.

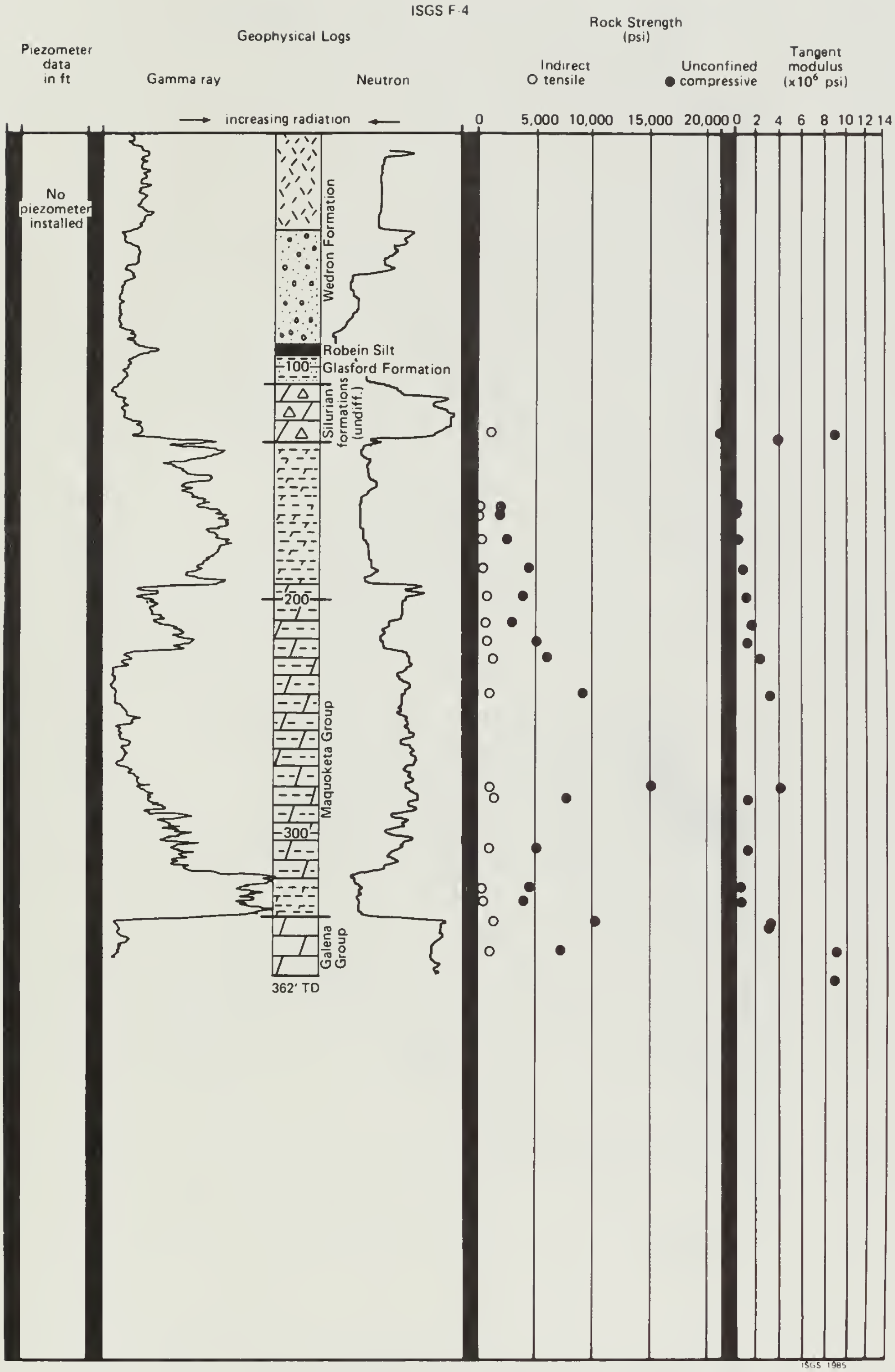


Figure 28 *continued.*

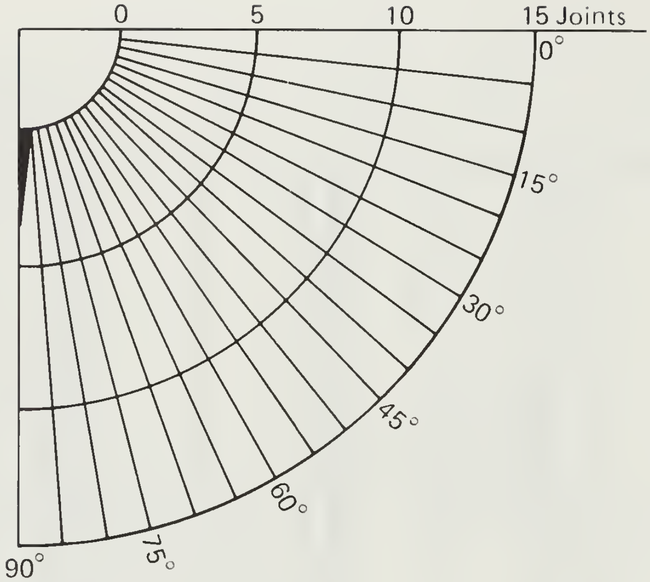


Figure 29

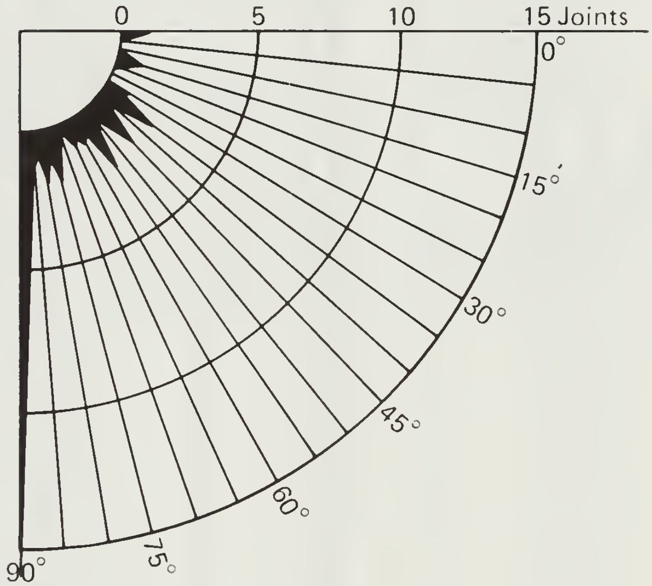
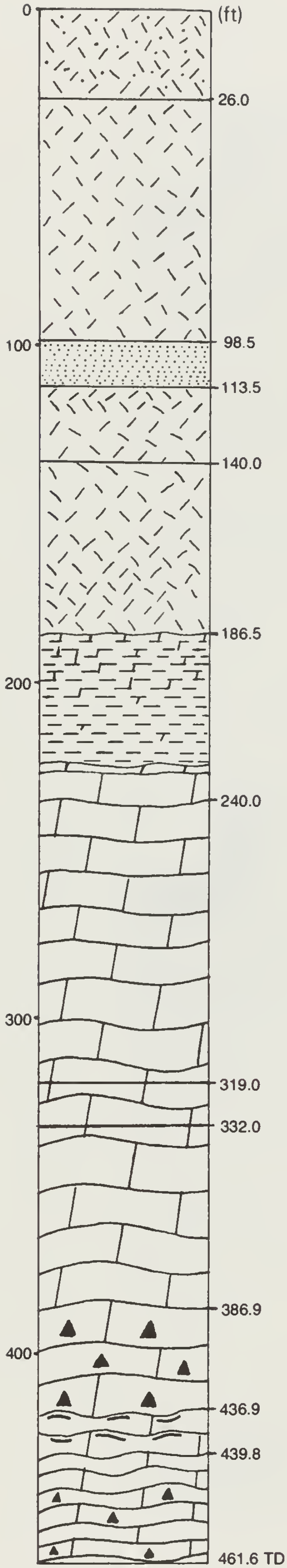


Figure 30

Dip diagrams of joints in Test Hole F-4:
29 18.6 feet of cored Silurian System strata.
30 205 feet of cored Maquoketa Group strata. (Soft sediment deformation features included.)



QUATERNARY SYSTEM
PLEISTOCENE SERIES
WEDRON FORMATION
MALDEN TILL MEMBER
Till and silt loam; gray, locally laminated (0.0–26.0 ft)
TISKILWA TILL MEMBER
Till; pinkish brown till (26.0–98.5 ft)

Brown, fine sandy silt (98.5–113.5 ft)

GLASFORD FORMATION
OREGON TILL MEMBER
Till; yellowish brown sandy clay loam (113.5–140.0 ft)
FAIRDALE TILL MEMBER
Till; brown silt loam (140.0–186.5 ft)

ORDOVICIAN SYSTEM
MAQUOKETA SHALE GROUP
Shale, olive gray, greenish gray, dolomitic, silty, fossiliferous, phosphatic; some minor dolomite beds; coarse-grained, speckled dolomite at base (186.5–240.0 ft)

GALENA DOLOMITE GROUP
WISE LAKE DOLOMITE FORMATION
Dolomite, yellowish brown, fine- to medium-grained, vuggy, pyritic; in wavy beds separated by thin brown and green shaly partings; bentonites at 319.0 and 332.0 ft (240.0–386.9 ft)

DUNLEITH DOLOMITE FORMATION
Dolomite, similar to above, but cherty (386.9–436.9 ft)

GUTTENBERG DOLOMITE FORMATION
Dolomite, yellowish brown, fine-grained, fossiliferous with reddish brown shaly partings (436.9–439.8 ft)

PLATTEVILLE DOLOMITE GROUP
Dolomite, buff, very fine-grained, burrowed and fossiliferous; thin wavy beds separated by thin brown shaly partings; some chert (439.8–461.6 ft)

Figure 31 Stratigraphic column for Test Hole F-5.

TEST HOLE ISGS F-5

Location: SW¼ NW¼ SW¼ SW¼ Section 1, T39N, R5E
Farm: The Illinois State Toll Highway Authority, De Kalb County
Surface elevation: 866 feet
Total depth: 462 feet

Stratigraphy

Bedrock

The stratigraphic column (fig. 31) shows the lithologies and depths of the drift and bedrock units encountered in F-5. The hole penetrated into the top of the Platteville Dolomite Group to a total depth of 461.6 feet. The units encountered (from top to bottom) are 186.5 feet of glacial drift, 53.5 feet of olive gray and greenish gray shale interbedded with light gray, coarse-grained, fossiliferous dolomite (Maquoketa Shale Group), 146.0 feet of yellowish brown, fine- to medium-grained, vuggy dolomite (Galena Dolomite Group; Wise Lake Dolomite Formation), 50.9 feet of yellowish brown, fine- to medium-grained, vuggy, cherty dolomite (Galena Dolomite Group; Dunleith Dolomite Formation), 2.9 feet of yellowish brown, fine-grained, fossiliferous, dolomite with reddish brown shaly partings (Galena Dolomite Group; Guttenberg Dolomite Formation), and 21.8 feet of very pale orange, very fine-grained, burrowed, fossiliferous, slightly vuggy and cherty dolomite (Platteville Dolomite Group; undifferentiated). Of note are two K-bentonite beds at 319.2 and 332.5 feet.

Glacial Drift

From top to bottom, the materials encountered include 5.0 feet of silty clay (Richland Loess), 21.0 feet of interbedded gray loamy till and laminated silty clay (Wedron Formation; Malden Till Member), 87.5 feet of pinkish brown laminated sand and silt; and pinkish brown loamy till (Wedron Formation; Tiskilwa Till Member), 26.5 feet of yellow brown loamy till, sand and gravel (Glasford Formation; Oregon Till Member (?)) and 46.5 feet of pinkish brown loam diamicton (Glasford Formation; Fairdale Till Member (?)).

Geophysical Logging

The temperature probe recorded the greatest fluctuation in the interval 180 to 200 feet (near the base of the casing) and at 430 to 450 feet (near the bottom of the test hole). These fluctuations were opposite fracture zones in the test hole and are related to patterns of ground water in the carbonate bedrock (table 3).

The neutron configuration indicates the highest moisture content between 100 to 105 feet opposite a sandy silt in the glacial drift. Very pronounced inflections are present on the gamma ray and neutron log at depths of 319 and 332 feet indicating bentonite beds (fig. 32).

The density log has pronounced inflections which are coincident with carbonate fracturing and a bentonite unit at 319 feet.

Pressure Testing

The results of the individual pressure tests for this boring are listed in table 18, and the range of hydraulic conductivity values for test intervals are shown graphically in figure 32. Borehole F-5 did not lose circulation during drilling.

Geotechnical Data

Bedrock

A slight increase in the number of fractures was encountered in the Maquoketa and Galena near the contact between these two units (figs. 32, 33, 34, and 35). Core recovery and the rock quality designation were both excellent with the lowest values of 98 and 96 percent, respectively, except for the first run, which had an 84 percent RQD value (tables 9 and 10, respectively).

Drift

The drift at F-5 is predominantly loam till with medium to high bearing capacity. The upper 27 feet, however, contains stratified silty clay and loam till with low to medium bearing capacity. The same conditions are found between 100 to 111 feet. The engineering properties of samples from this hole are shown in table 19.

Table 18. Hydraulic conductivity (cm/sec) for Test Hole ISGS F-5 *

Test intervals (ft)	P_1	P_2	P_3	P_2	P_1
460-439	$2.2x10^{-6}$	$1.9x10^{-6}$	$1.3x10^{-5}$	$1.9x10^{-6}$	**
439-418	$2.2x10^{-6}$	$2.6x10^{-6}$	$2.4x10^{-6}$	$1.9x10^{-6}$	**
355-334	$2.0x10^{-6}$	$1.3x10^{-6}$	$2.0x10^{-6}$	$1.3x10^{-6}$	0
271-250	0	$6.0x10^{-7}$	$1.4x10^{-6}$	0	**
208-187	0	**	$5.8x10^{-6}$	$7.0x10^{-7}$	0

* P_1 = 40 psi,
P_2 = 70 psi,
P_3 = 100 psi

**Not tested

Table 19. Engineering properties of drift for Test Hole ISGS F-5

Depth of sample (ft)	Unit description	N (blows per ft)	qp+ (tons/ft^2)	Moisture content (%)	Dry density (gm/cm^3)	Moist density (gm/cm^3)	Grain Size Gvl** (%)	Grain Size Sand* (%)	Grain Size Silt* (%)	Grain Size Clay* (%)	Unified soil classification
3.5-5	gray,	24	---	---	---	---	0.5	10.4	60.8	28.8	ML
8.5-10	laminated	18	2.3	11.5	2.32	2.63	15.6	32.5	48.6	18.9	ML
	silt loam,			12.3							
13.5-15	and loam	20	---	17.5	2.04	2.47	0.5	45.0	54.5	3.5	ML
	till			17.2							
19.0-19.3		22	---	15.5	---	---	6.6	32.8	45.7	21.5	CL
	gray silt			11.7							
23.5-25	loam	22	3.5	10.9	2.02	2.29	25.8	23.4	54.6	22.0	CL
28.5-30		10	0.8	11.9	2.24	2.55	27.9	38.1	36.1	25.8	CL
				11.6							
33.5-35		16	2.0	---	---	---	11.4	37.2	36.8	26.0	CL
38.5-40		12	1.25	12.0	2.26	2.57	6.6	42.6	34.0	23.4	CL
				10.7							
43.5-45	pinkish	18	1.65	11.0	---	---	7.2	37.0	38.0	25.0	CL
	brown loam			11.0							
48.5-50	till	22	1.25	11.4	2.25	2.54	6.8	38.7	38.9	22.4	CL
				10.7							
53.5-55		34	3.9	10.3	2.19	2.40	5.8	37.1	35.1	27.8	CL
				10.4							
58.5-60		28	2.6	10.5	---	---	12.6	35.0	40.2	24.8	CL
63.5-65		40	---	---	---	---	4.3	36.9	36.7	26.4	CL
68.5-70		44	2.5	10.8	2.16	2.37	4.6	34.9	38.9	26.2	CL
				10.9							
73.5-75		32	3.35	10.7	---	---	14.1	34.8	38.6	26.6	CL
78.5-80		54	<--------NO RECOVERY-->								CL
83.5-85		32	2.5	10.8	2.24	2.51	25.2	35.2	38.5	26.3	CL
				10.7							
88.5-90		30	<--------NO RECOVERY-->								CL

Table 19. *continued*

Depth of sample (ft)	Unit description	N (blows per ft)	qp+ (tons/ft^2)	Moisture content (%)	Dry density (gm/cm^3)	Moist density (gm/cm^3)	Grain Size Gvl** (%)	Grain Size Sand* (%)	Grain Size Silt* (%)	Grain Size Clay* (%)	Unified soil classification
93.5-95	pinkish	36	2.9	10.4	---	---	16.0	36.3	38.0	25.7	CL
	brown loam			10.7							
98.5-100	till (cont)	54	4.5	8.1	---	---	9.6	44.4	36.1	19.5	CL
103.5	pinkish		---	18.2	---	---	2.8	2.9	85.9	11.2	ML
104.0	brown,	22	---	---	---	---	0.0	86.7	9.3	4.0	ML
108.5-110	laminated	86	---	18.4	1.86	2.28	0.0	61.6	34.8	3.6	ML
	sand,silt			17.3							
113.5-115		62	---	---	---	---	27.3	42.3	38.5	19.2	CL
118.5-120	yellowish	52	---	9.3	2.36	2.62	21.4	44.5	35.8	19.7	CL
	brown			10.1							
123.5-125	sandy	92	<------NO RECOVERY------>								CL
130.0-131.5	clay loam		2.65	9.8	2.28	2.52	10.4	47.7	24.5	27.8	CL
	till			10.1							
133.5-135			<------RIBBON------>				22.7	51.1	17.7	31.2	CL
138.5-140			<------SMALL SAMPLE------>								CL
143.5-145			<------SMALL SAMPLE------>								CL
153.5-155	brown silt		<------NO SAMPLE------>								CL
158.5-160	loam till		4.25	9.1	2.33	2.57	7.4	28.8	56.3	14.9	CL
				9.2							
168.5-170		86	2.25	9.5	2.24	2.48	4.1	35.6	48.6	15.8	CL
				10.3							
178-180			<------NO RECOVERY------>								CL
	bedrock										

*percentage of < 2-mm fraction
**percentage of whole sample
+as measured by pocket penetrometer

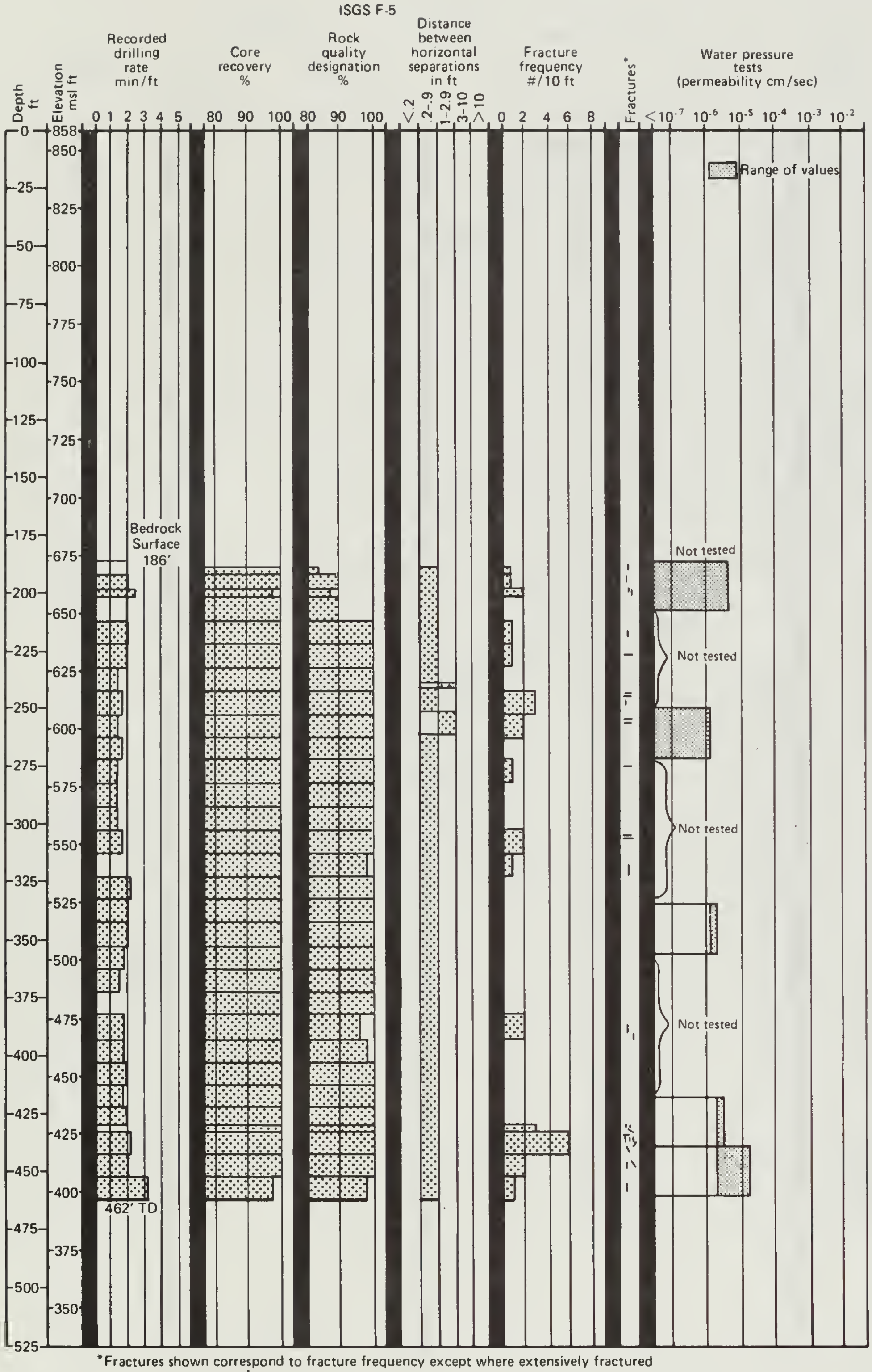


Figure 32 Summary diagram of data for Test Hole F-5.

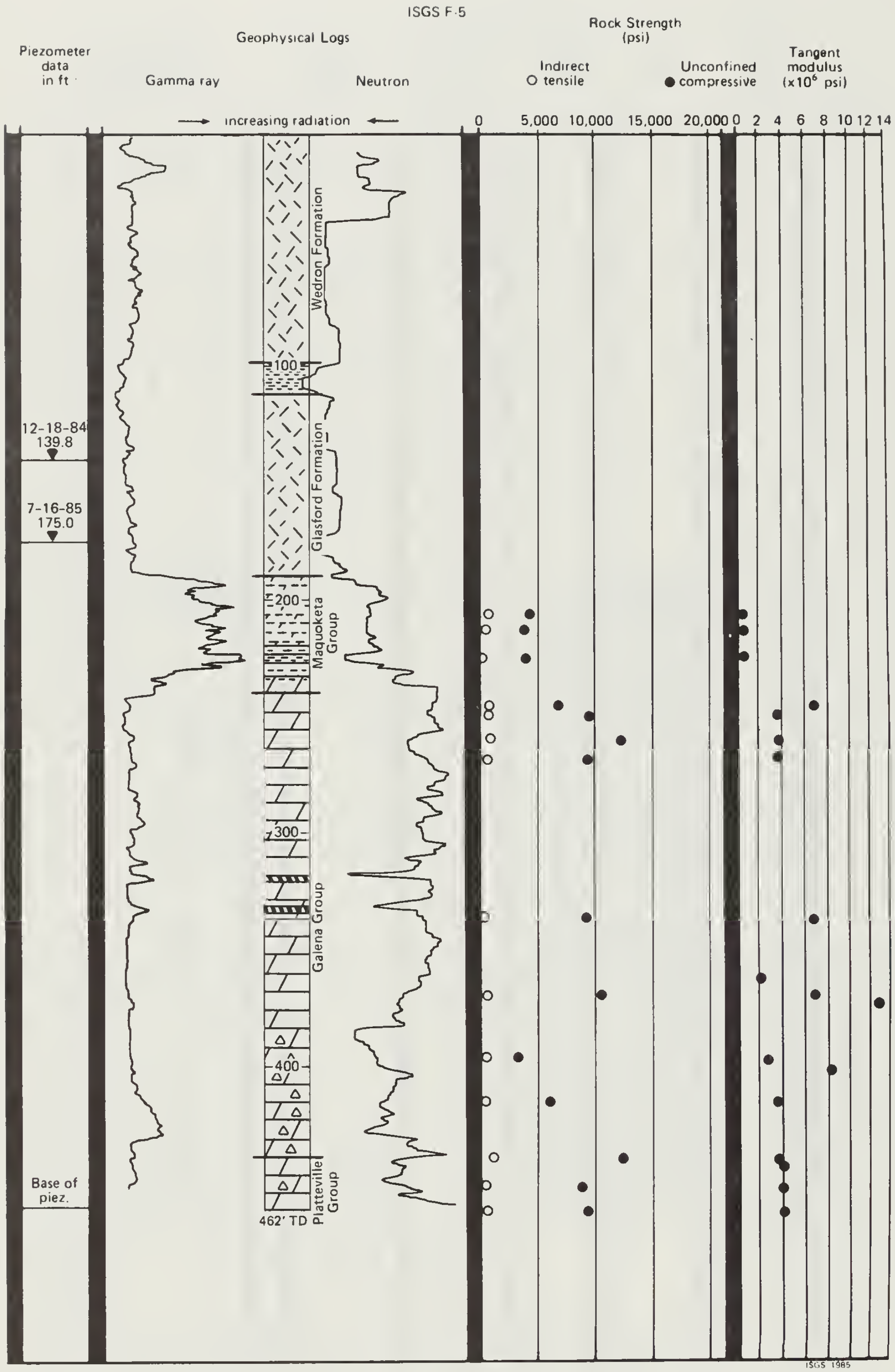


Figure 32 *continued.*

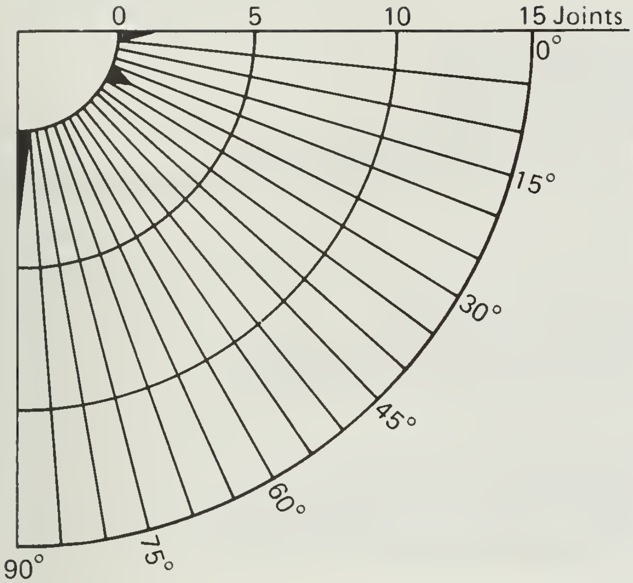


Figure 33

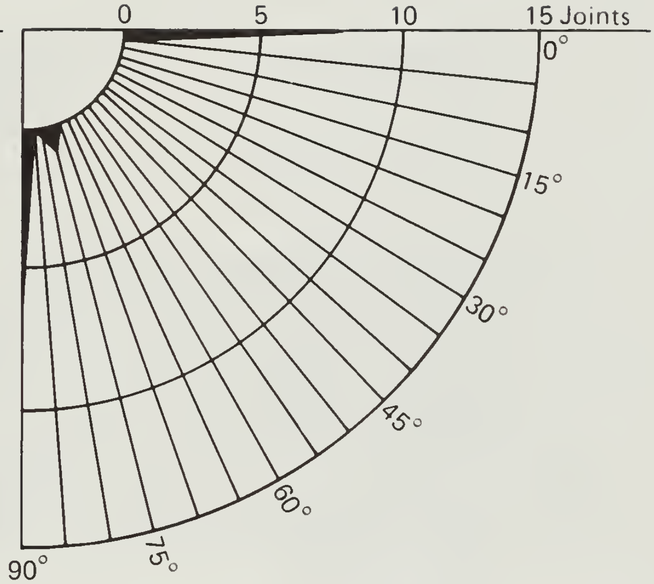


Figure 34

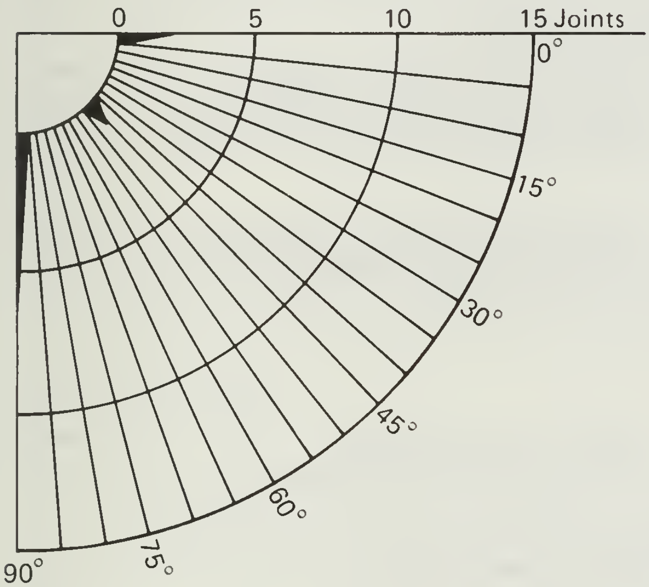
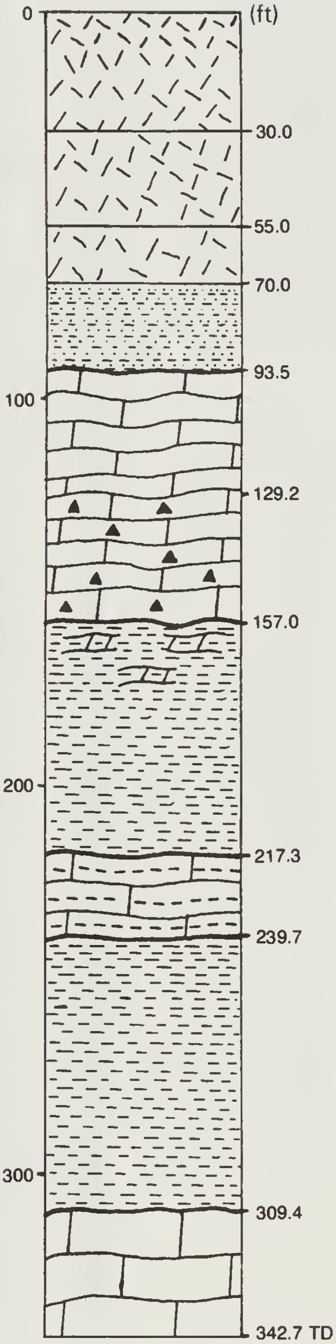


Figure 35

Dip diagrams of joints in Test Hole F-5:
33 40 feet of cored Maquoketa Group strata.
34 200 feet of cored Galena Group strata.
35 22 feet of cored Platteville Group strata.



QUATERNARY SYSTEM
PLEISTOCENE SERIES
WEDRON FORMATION
YORKVILLE TILL MEMBER
Till; gray silty clay loam interbedded with gray silt loam (0.0–30.0 ft); till; gray silt loam (30.0–55.0 ft); till; dark gray clay (55.0–70.0 ft)

MALDEN TILL MEMBER (?)
Silt and sand; grayish brown, laminated—interbedded with till; yellow brown silt loam at base (70.0–93.5 ft)

SILURIAN SYSTEM
KANKAKEE DOLOMITE FORMATION
Dolomite, light olive gray, fine-grained vuggy, pyritic, glauconitic; thin wavy beds separated by green shale partings (93.5–129.2 ft)

ELWOOD DOLOMITE FORMATION
Dolomite, as above, but cherty (129.2–157.0 ft)

ORDOVICIAN SYSTEM
MAQUOKETA SHALE GROUP
Shale, greenish gray, purple, grayish red, silty, dolomitic; some dolomite, light olive gray and greenish gray, medium grained in the upper 30 feet (157.0–217.3 ft)

Dolomite, light olive gray to olive gray, dark gray speckled, argillaceous, fossiliferous, some stylolites, vuggy (217.3–239.7 ft)

Shale, olive gray, dolomitic, silty; greenish gray in last 2 feet (239.7–309.4 ft)

GALENA DOLOMITE GROUP
WISE LAKE DOLOMITE FORMATION
Dolomite, pale yellow brown, fine- to medium-grained, vuggy, some vugs filled with calcite, styolites (309.4–342.7 ft)

Figure 36 Stratigraphic column for Test Hole F-6.

TEST HOLE ISGS F-6

Location: NE¼ NE¼ SW¼ NE¼ Section 23, T37N, R8E
Farm: G. Hettrick Farm, Kendall County
Surface elevation: 712 feet
Total depth: 343 feet

Stratigraphy

Bedrock
The stratigraphic column (fig. 36) shows the lithologies and depths of the drift and bedrock units encountered in hole F-6. The hole penetrated into the Wise Lake Dolomite Formation of the Galena Dolomite Group to a total depth of 342.7 feet. The units encountered (from top to bottom) are 93.5 feet of glacial drift, 35.7 feet of light gray, fine-grained, dolomite (Kankakee Dolomite Formation), 27.9 feet of light gray, fine-grained, cherty dolomite (Elwood Dolomite Formation), 152.3 feet of greenish gray, purple, grayish red and olive gray shale interbedded with light gray to olive gray, fine- to coarse-grained, argillaceous dolomite and minor limestone (Maquoketa Shale Group), and 33.3 feet of yellowish brown, fine- to medium-grained, vuggy dolomite (Galena Dolomite Group; Wise Lake Dolomite Formation). Of note is the presence of limestone beds and red and purple shales within the Maquoketa Group.

Glacial Drift
From top to bottom there was 30.0 feet of interbedded gray till and laminated gray sand and gravel 40.0 feet of dark gray, laminated clayey silt and silty clay till with fine shale chips, 19.5 feet of grayish brown, laminated, silt and sand, and 4.0 feet of yellow brown silty clay till.

Geophysical Logging
Figure 37 shows the gamma-ray and neutron logs run in borehole F-6. The density log indicates a greater density in the Silurian System between 95 to 126 feet the dolomite contains fewer impurities.

Pressure Testing
The results of the individual pressure tests for this boring are listed in table 20, and the range of hydraulic conductivity values for test intervals is shown graphically in figure 37. Borehole F-6 temporarily lost or had reduced circulation at four levels in the bedrock.

Geotechnical Data

Bedrock
The number of fractures encountered was small with slight concentrations in the upper 30 feet of the Silurian and near the contact between the Maquoketa and Galena (figs. 37, 38, 39, and 40). Both the core recovery and rock quality designation was excellent except for one run where both were good with 84 percent values (tables 9 and 10, respectively).

Drift
The drift at F-6 is composed of chiefly interbedded silty till (high bearing capacity) and poorly graded sand (low bearing capacity). Between 32.5 to 55.0 feet is a thick till layer; below this, the till becomes stratified, but the bearing capacity remains high. The engineering properties of samples from this hole are shown in table 21.

Table 20. Hydraulic conductivity (cm/sec) for Test Hole ISGS F-6 *

Test intervals (ft)	P_1	P_2	P_3	P_2	P_1
332-311	0	$1.2x10^{-6}$	$1.8x10^{-6}$	$1.2x10^{-6}$	$1.9x10^{-6}$
311-290	0	$3.6x10^{-6}$	$1.4x10^{-5}$	$3.6x10^{-6}$	0
290-269	0	0	$1.6x10^{-5}$	0	0
236-215	$1.5x10^{-5}$	$1.4x10^{-4}$	$1.2x10^{-4}$	$1.4x10^{-4}$	$1.7x10^{-4}$
201-180	0	0	0	0	0
180-159	0	$1.2x10^{-6}$	$9.0x10^{-7}$	$1.2x10^{-6}$	0
159-138	0	0	0	0	0
138-117	$6.7x10^{-4}$	$5.6x10^{-4}$	$4.8x10^{-4}$	$5.6x10^{-4}$	$6.8x10^{-4}$
117-96	0	0	0	0	0

* Below a depth of 159 feet: P_1 = 35 psi, P_2 = 70 psi, P_3 = 100 psi

Above depth of 159 feet: P_1 = 10 psi, P_2 = 30 psi, P_3 = 50 psi

Table 21. Engineering properties of drift for Test Hole ISGS F-6

Depth of sample (ft)	Unit description	N (blows per ft)	qp+ (tons/ft^2)	Moisture content (%)	Dry density (gm/cm^3)	Moist density (gm/cm^3)	Grain Size				Unified soil classification
							Gvl** (%)	Sand* (%)	Silt* (%)	Clay* (%)	
3.5-5	gray silty	<-----	-----	-----NO SAMPLE-----	-----	-----	-----	-----	-----	----->	ML
8.5-10	clay loam	30	>4.5	8.5	1.93	2.45	12.5	14.8	46.9	38.3	CL
	till			8.5							
				8.6							
13.5-15	gray silt	14	<0.75	8.4	---	---	0.0	2.2	59.8	38.0	ML
	loam and sand										
18.5-20	gray till	38	>4.5	9.0	2.14	2.91	28.3	26.1	42.4	31.5	CL
				9.1							
				9.0							
23.5-25	brownish gray	22	0.9	---	---	---	---	---	---	---	SW
28.5-30	sand and	26	>4.5	9.0	---	---	---	---	---	---	SW
	gravel; thin										
	till bed										
32.5-35		34	>4.5	8.8	1.95	2.68	8.2	18.5	46.3	35.2	CL
				9.0							
	gray pebbly			8.6							
38.5-40	silt loam	26	2.25	8.7	---	---	8.2	16.3	45.6	38.1	CL
43.5-45	till	42	2.60	8.8	2.21	2.59	6.9	18.5	46.8	34.7	CL
				8.8							
	gray pebbly										
	silt loam										
48.5-50	till (cont)	44	>4.5	9.0	---	---	7.2	22.8	43.4	33.8	CL
53.5-55		64	>4.5	9.0	---	---	7.8	19.4	44.0	36.6	CL
58.5-60			---	8.1	---	---	3.6	9.2	31.0	59.8	CL
53.5-65	dark gray,	62	4.3	8.1	1.77	2.09	0.9	4.0	25.5	70.5	CL
	clay till,		8.2								
	laminated top		8.2								
68.5-70		86	>4.5	8.6	---	---	2.2	8.7	26.7	64.6	CL
73.5-75	grayish brown		<0.5	8.4	---	---	0.0	15.0	81.7	3.3	ML
78.5-80	silt; lamin-	42	<0.5	8.2	---	---	0.0	74.9	22.0	3.1	SW
	ated very										
	fine sand										
83.5-85	gray sand	70	<0.5	8.1	---	---	0.0	89.2	7.0	3.8	SP
88.5-90	laminated,		---	9.1	---	---	5.0	27.7	57.9	14.4	CL
	yellowish										
	brown silt and										
	fine sand loam										
	bedrock										

*percentage of < 2-mm fraction
**percentage of whole sample
+as measured by pocket penetrometer

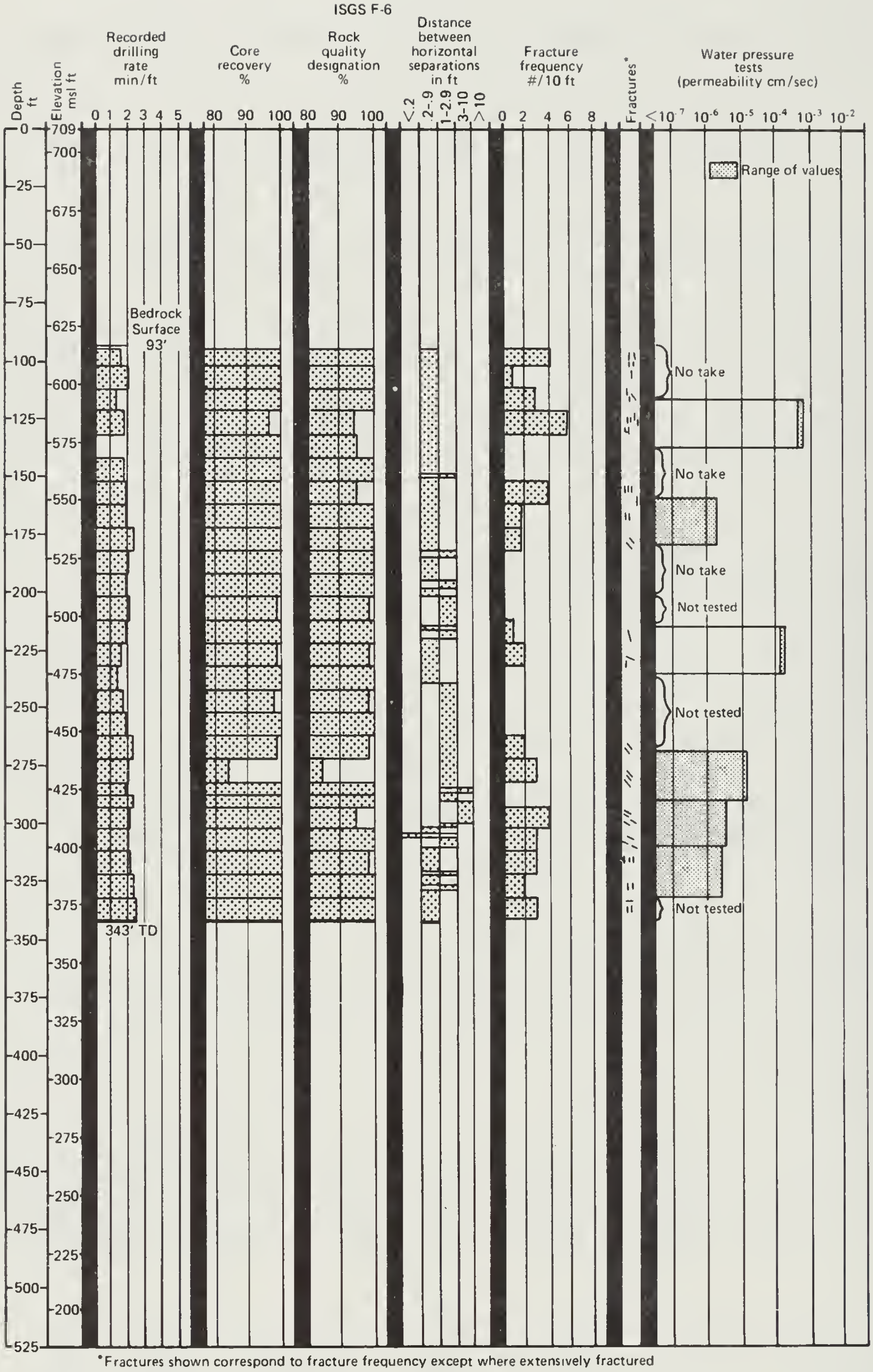


Figure 37 Summary diagram for Test Hole F-6.

Figure 37 *continued.*

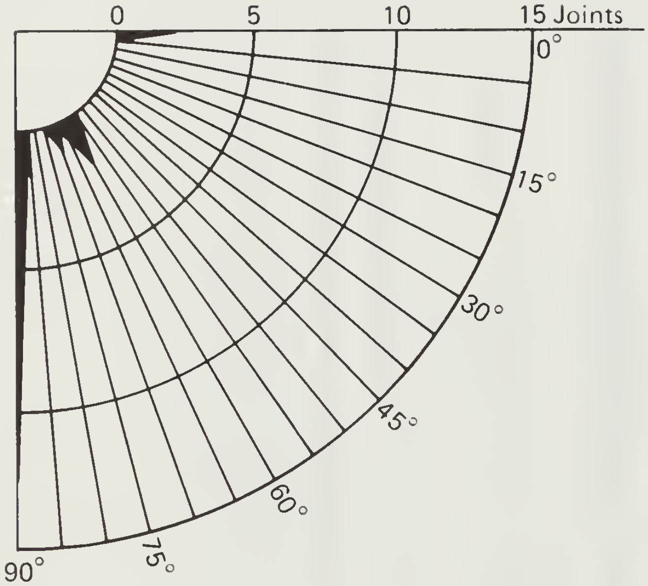


Figure 38

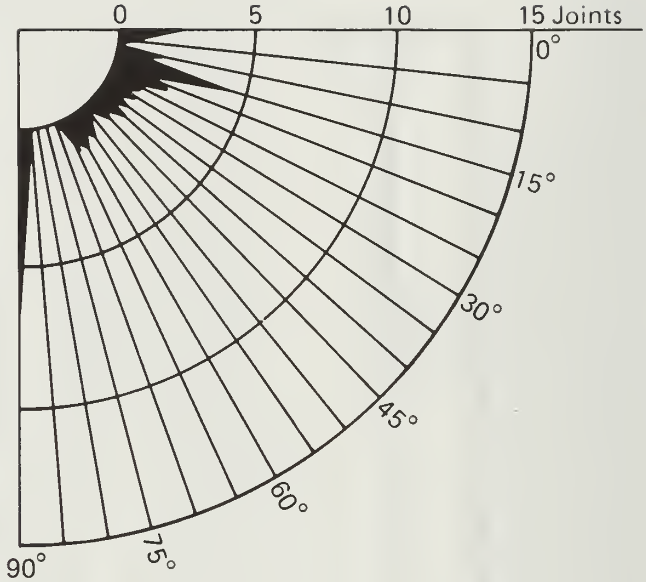


Figure 39

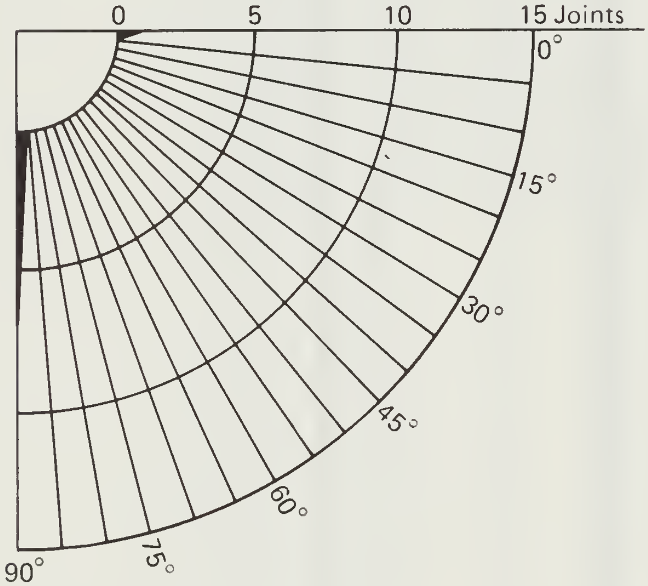
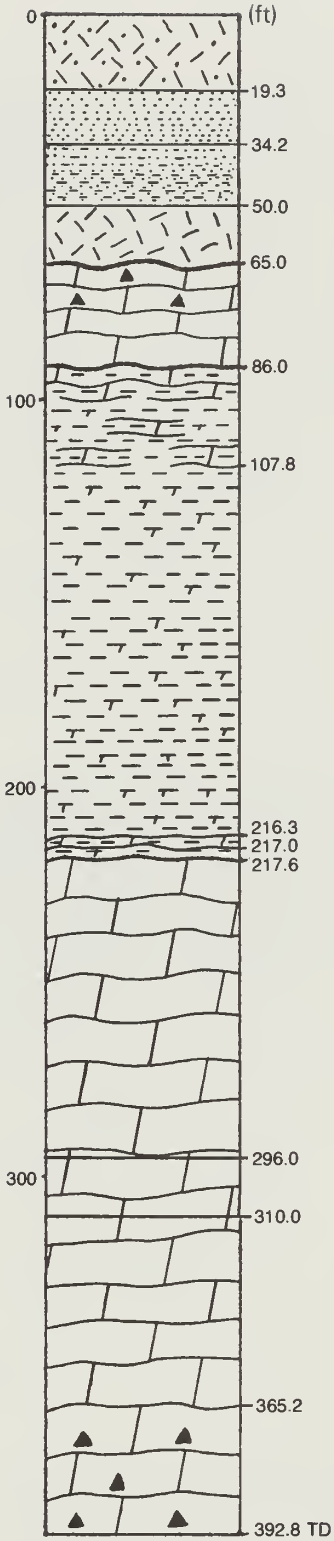


Figure 40

Dip diagrams of joints in Test Hole F-6:
38 91 feet of cored Silurian system strata.
39 122 feet of cored Maquoketa Group strata.
40 33 feet of cored Galena Group strata.



QUATERNARY SYSTEM
PLEISTOCENE SERIES
WEDRON FORMATION
MALDEN TILL MEMBER
Till; gray silt loam (0–19.3 ft)

TISKILWA TILL MEMBER
Fine to medium sand; pinkish gray (19.3–34.2 ft); silty clay, silt, and fine sand (34.2–50.0 ft); till; pinkish brown sandy loam and loam till (50.0–65.0 ft)

SILURIAN SYSTEM
ELWOOD DOLOMITE FORMATION
Dolomite, yellowish gray, fine-grained; thin wavy beds separated by greenish gray shale partings; some chert (65.0–86.0 ft)

ORDOVICIAN SYSTEM
MAQUOKETA SHALE GROUP
Dolomite, yellowish gray, speckled dark gray coarse-grained, slightly argillaceous; minor greenish gray shale beds (86.0–107.8 ft)

Shale, greenish gray, olive gray dolomitic, silty, burrowed to laminated; minor dolomite beds; light olive gray, greenish gray, fine-grained, argillaceous, burrowed; coarse-grained dolomite in large burrow at base (107.8–217.6 ft)

GALENA DOLOMITE GROUP
WISE LAKE DOLOMITE FORMATION
Dolomite, pale yellowish brown, fine- to medium-grained, vuggy, pyritic; wavy beds separated by thin shaly partings, fossiliferous (gastropods); bentonite beds at 296.0 and 310.0 feet (217.6–365.2 ft)

DUNLEITH DOLOMITE FORMATION
Dolomite—as above, but with abundant white chert (365.2–392.8 ft)

Figure 41 Stratigraphic column for Test Hole F-7.

TEST HOLE ISGS F-7

Location: NE¼ NE¼ NE¼ NE¼ Section 20, T39N, R6E
Farm: Lone Grove Forest Preserve; Forest Preserve District of Kane County
Surface elevation: 796 feet
Total depth: 393 feet

STRATIGRAPHY

Bedrock

The stratigraphic column (fig. 41) shows the lithologies and depths to the drift and bedrock units encountered in hole F-7. The hole penetrated into the Dunleith Dolomite Formation of the Galena Group to a total depth of 392.8 feet. The units encountered (from top to bottom) are 65.0 feet of glacial drift, 21.0 feet of light gray, fine-grained, cherty dolomite, 131.6 feet of greenish gray and olive gray shale interbedded with minor light gray, fine- to coarse-grained dolomite (Maquoketa Shale Group), 147.5 feet of yellowish brown, fine- to medium-grained, cherty dolomite (Galena Dolomite Group; Dunleith Dolomite Formation). Of note are two K-bentonite (altered volcanic ash) beds encountered in the Wise Lake at 296 and 310 feet.

Glacial Drift

From top to bottom, the hole penetrated 19.3 feet of gray silty loam till capped by gray silt (Malden Till Member), 14.9 feet of pinkish gray fine and medium sand (Tiskilwa Till Member), 15.8 feet of pinkish gray, laminated, silty clay, silt and fine sand (Tiskilwa Till Members), and 15.0 feet of pinkish brown gray silty clay till (Tiskilwa Till Member).

Geophysical Logging

The sharp peak at a depth of 296 feet on the neutron log (fig. 42) and the matching indentation on the natural gamma log mark one of the persistent bentonite beds commonly present in the Galena Group.

Pressure Testing

The results of the individual pressure tests for this boring are listed in table 22, and the range of hydraulic conductivity values for test intervals are shown graphically in figure 42. Borehole F-7 lost some circulation of the drilling fluid in the upper 40 feet of bedrock and at a level of about 376 feet below the ground surface.

GEOTECHNICAL DATA

Bedrock

No highly fractured zones were encountered in this hole. Nearly all the fractures encountered had angles from 80 to 90° from horizontal (figs. 42, 43, 44, and 45).

Core recovery was excellent throughout the entire hole with the lowest value of 98 percent found in two core runs (table 9). The rock quality designation (RQD) was also excellent throughout the length of the core with the lowest values of 92 and 93 percent encountered in two core runs (table 10). The average RQD values for this hole were 100 percent for the Silurian, 99.7 percent for the Maquoketa and 99 percent for the Galena and Platteville.

Drilling rate times generally decreased by almost a minute after the bit was changed at a depth of about 130 feet (table 8 and fig. 42).

Drift

The drift at F-7 is interbedded gravel and sand, silty loam till and stratified silt. No unconfined compressive strength tests were done, but the relatively high water content from 0 to 45 feet indicates low to medium bearing capacity. The lowermost 45 to 68.5 feet, on the other hand, has low water content and is a compact, loamy till, indicating high to very high bearing capacity. The engineering properties of samples from this hole are shown in table 23.

Table 22. Hydraulic conductivity (cm/sec) for Test Hole ISGS F-7 *

Test intervals (ft)	P_1	P_2	P_3	P_2	P_1
384-363	5.5×10^{-6}	4.4×10^{-6}	4.3×10^{-6}	4.4×10^{-6}	5.5×10^{-6}
363-342	5.5×10^{-6}	3.0×10^{-6}	2.1×10^{-6}	3.0×10^{-6}	5.5×10^{-6}
321-300	0	1.5×10^{-6}	3.2×10^{-6}	1.5×10^{-6}	0
230-209	0	0	2.1×10^{-6}	0	0
91-70	2.5×10^{-4}	2.6×10^{-4}	2.4×10^{-4}	2.3×10^{-4}	2.7×10^{-4}

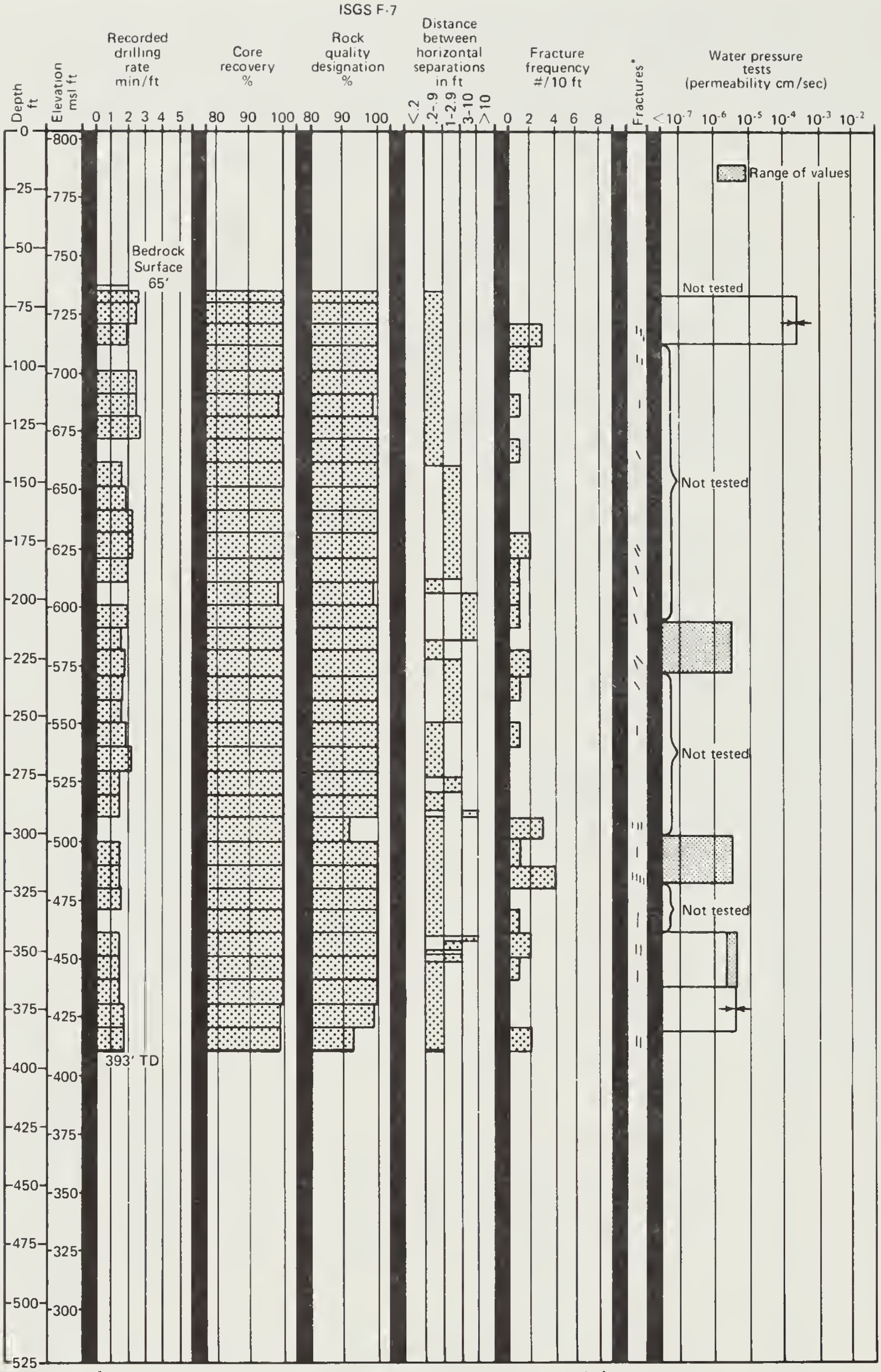
* Below a depth of 159 feet: P_1 = 35 psi, P_2 = 70 psi, P_3 = 100 psi

Above depth of 159 feet: P_1 = 10 psi, P_2 = 30 psi, P_3 = 50 psi

Table 23. Engineering properties of drift for Test Hole F-7

Depth of sample (ft)	Unit description	N (blows per ft)	qp+ (tons/ft^2)	Moisture content (%)	Dry density (gm/cm^3)	Moist density (gm/cm^3)	Grain Size: Gvl** (%)	Sand* (%)	Silt* (%)	Clay* (%)	Unified Soil Classification
8.5-10	loam	28	---	12.2	---	---	5.4	24.7	49.7	25.6	ML
13.5-15		24	---	13.2	---	2.52	6.0	15.6	65.4	19.0	CH
	gray silt			16.2							
	loam till			16.0							
18.5-20		44	---	15.3	---	---	0.0	70.4	25.6	4.0	SW
23.5-25	firm grayish	40	---	---	---	---	58.4	75.4	18.3	6.3	GP
28.5-30	pink sand	54	---	---	---	---	0.0	75.1	20.5	4.4	SW
33.5-35		76	---	17.8	---	---	0.0	4.9	86.7	8.4	ML
38.5-40	laminated		---	18.6	---	---	1.5	2.2	79.7	18.1	ML
	silt loam										
	till						0.0	0.8	69.3	29.9	ML
43.5-45	pink sandy	54	---	17.9	---	---	9.1	62.6	26.7	10.7	SW
48.5-50	loam till	26	---	11.4	---	---	20.8	46.9	33.3	19.8	CL
53.5-55		60	---	11.8	2.11	2.39	5.2	23.7	40.3	36.0	CL
				12.0							
	pinkish			11.3							
58.5-60	brown, gray	56	---	10.7	---	---	25.8	32.6	38.7	28.7	CL
63.5-65	silty loam	40	---	10.4	2.22	2.56	6.1	42.6	33.7	23.7	CL
	till			9.8							
	bedrock										

*percentage of < 2-mm fraction
**percentage of whole sample
+as measured by pocket penetrometer



*Fractures shown correspond to fracture frequency except where extensively fractured

Figure 42 Summary diagram for Test Hole F-7.

Figure 42 *continued*

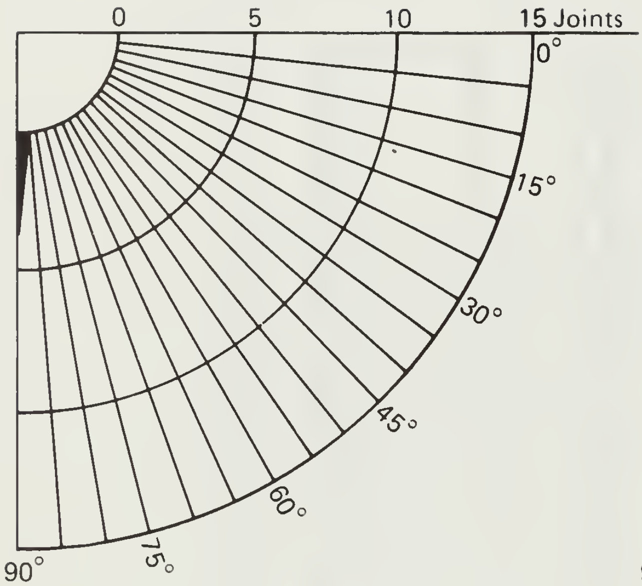


Figure 43

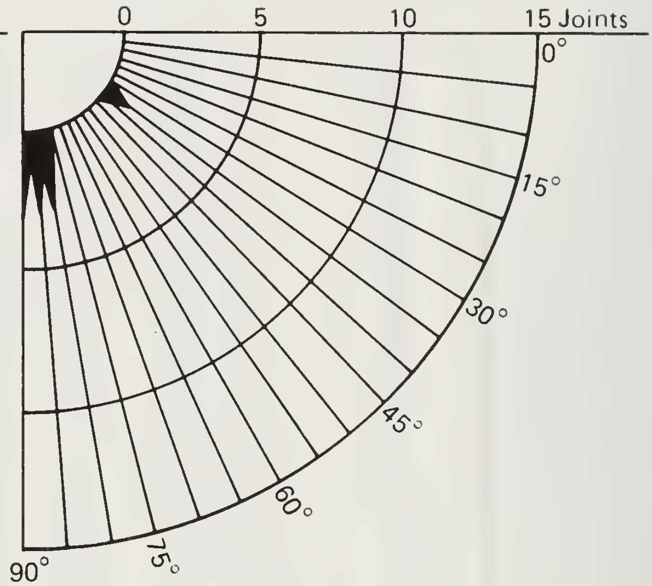


Figure 44

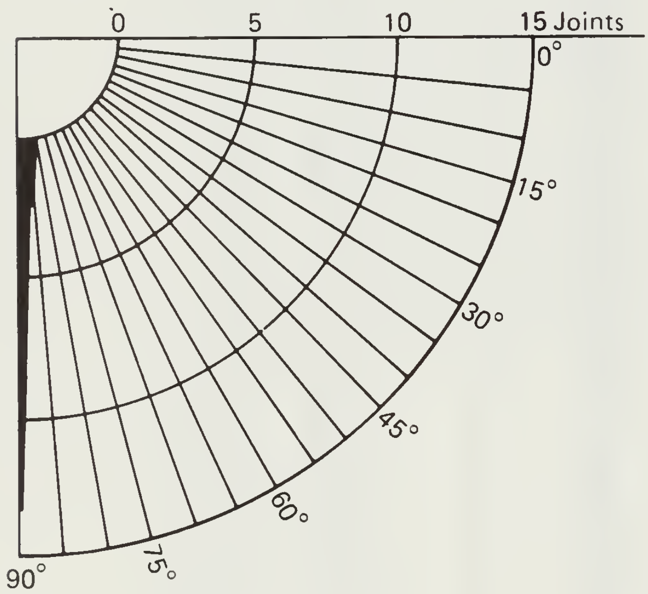
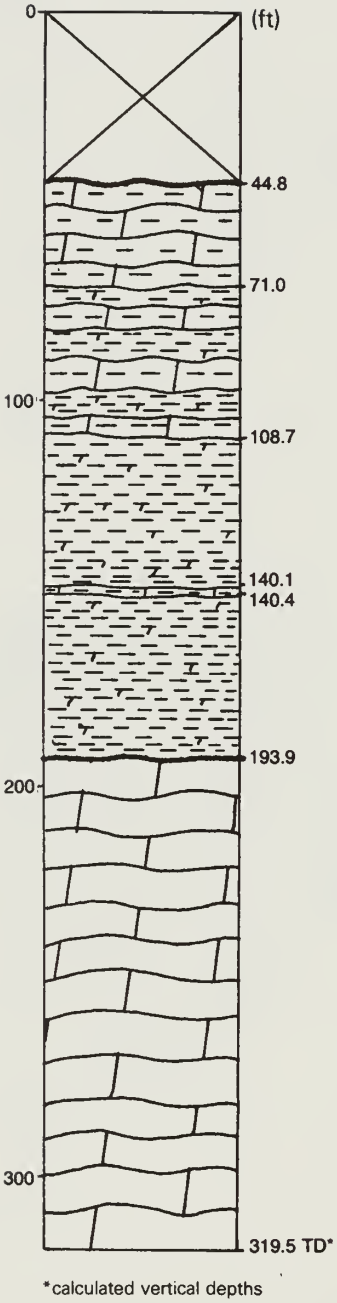


Figure 55

Dip diagrams for joints in Test Hole F-7:

43 17 feet of cored Silurian System strata.
44 131 feet of cored Maquoketa Group strata.
45 176 feet of cored Galena Group strata.



QUATERNARY SYSTEM

PLEISTOCENE SERIES

Not recovered

ORDOVICIAN SYSTEM

MAQUOKETA SHALE GROUP

Dolomite, light olive gray, speckled dark gray fine- to coarse-grained, slightly argillaceous; wavy beds separated by olive gray shaly partings, fossiliferous, slightly vuggy; grades to interbedded greenish gray shale and dolomite (44.8–108.7 ft)

Shale, olive gray, silty, dolomitic to very dolomitic, fossiliferous (108.7–140.1 ft)

Dolomite, light olive gray, speckled and mottled dark gray, coarse-grained, vuggy, fossiliferous (140.1–140.4 ft)

Shale, olive gray, dolomitic, silty, some fossiliferous (140.4–192.9 ft); greenish gray shale (44.8–193.9 ft)

GALENA DOLOMITE GROUP

WISE LAKE DOLOMITE FORMATION

Dolomite, pale yellow brown mottled medium dark gray, fine- to medium-grained, vuggy, pyritic, fossiliferous, some styolites (193.9–319.5 ft)

Figure 46 Stratigraphic column for Test Hole F-8.

TEST HOLE ISGS F-8

Location: SE¼SW¼ SW¼ Section 10, T37N, R6E
Farm: A. Wykes Farm, Kendall County
Surface elevation: 668 feet
Total depth: 320 ft

Stratigraphy

Borehole F-8 was drilled at a 30° angle from vertical. Due to the difficulty in sampling at this angle no samples of the drift were collected and pressure tests also were not performed. The stratigraphic column (fig. 46) shows the lithologies and calculated vertical depth to the rock units encountered in F-8. The hole penetrated into the Wise Lake Dolomite Formation to a total depth of 319.5 feet (calculated vertical depth). The hole penetrated (from top to bottom) 44.8 feet of glacial drift, 149.1 feet of olive gray shale interbedded with light gray, fine- to coarse-grained, fossiliferous, vuggy, argillaceous dolomite (Maquoketa Shale Group), and 125.6 feet of yellowish brown, fine- to medium-grained, vuggy, fossiliferous dolomite (Galena Dolomite Group; Wise Lake Dolomite Formation).

Geophysical Logging

The gamma-ray neutron log clearly reflects the strata encountered (fig. 47). From the total depth to 223 feet on the logs of the Galena Group is observed the characteristically low gamma emissions and low porosity indicated on the neutron log. From 223 feet up to 164 feet the purer shale at the base of the Maquoketa Group exhibits high gamma emissions and high thermal neutron activity caused by the hydrogen present in the clay minerals, its dominant constituent. From 164 feet to the top of bedrock at about 52 feet the Maquoketa becomes increasingly dolomitic. The dolomite beds show on these logs as zones of low gamma emissions and lower neutron activity (deflections to the right). No significant features are evident in the Pleistocene section.

Geotechnical Data

Bedrock

Borehole F-8 was an angle hole drilled at a 30° angle from vertical towards the east. This angle hole was designed to investigate the nature of the joints in the bedrock at depth. A different drill rig with a hydraulically driven Kelly table was used for this hole rather than the direct mechanical drive on the rig used for the other holes. The hydraulic drive and drilling angle caused the drilling rates to be slower than usual (fig. 47).

Borehole F-8 did not lose circulation during drilling. More closely spaced joints were encountered in the Galena compared to those encountered in the Maquoketa. The average distance between individual joint sets in the Maquoketa was 7.95 feet. In the Galena the average distances between the joints in the northwest and northeast directions were 2.33 and 2.62 feet, respectively.

The 15 joint surfaces encountered in the Maquoketa were 73 percent wavy and 27 percent smooth; among the asperites 80 percent were rough and 20 percent smooth. The 53 joint surfaces encountered in the Galena were 83 percent wavy and 17 percent planar; among the asperites 87 percent were rough and 13 percent smooth. Only 5 of the 53 joints in the Galena showed some minor discoloration.

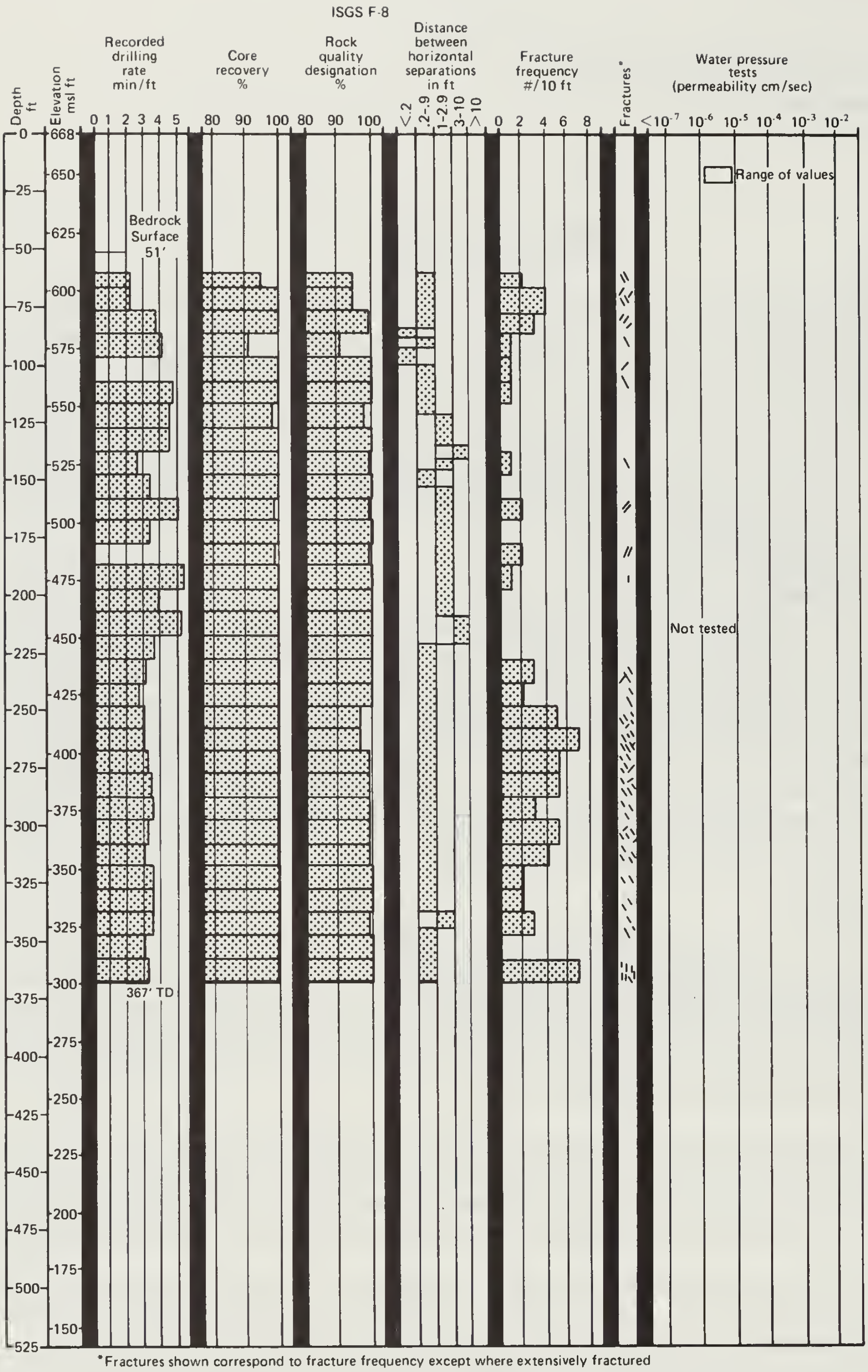


Figure 47 Summary diagram for angled Test Hole F-8 (shown are drilled depths not calculated vertical depths).

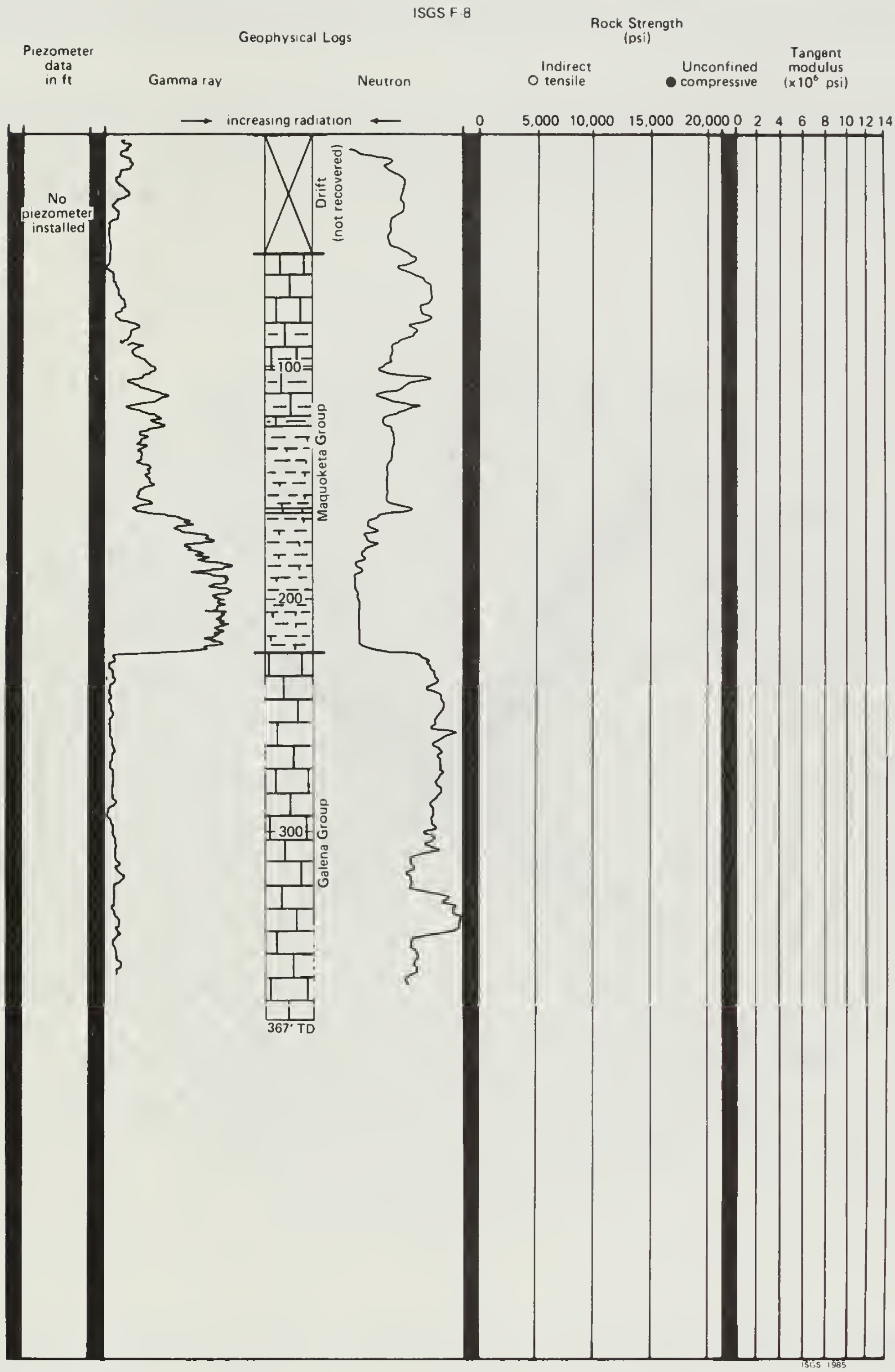


Figure 47 *continued.*

The joint orientations (fig. 48) closely match those found in the Meyers Material Company quarry near Big Rock, Illinois (fig. 49) found by Foote (1982) in his study of joint directions in northeastern Illinois and northwestern Indiana.

Core recovery and RQD values were excellent with the closest values in the upper 40 to 50 feet of the bedrock. Here the values are as low as 91 percent in one core run. The rest of the core recovery have values of 97 percent and higher throughout the rest of the core. The average RQD values for the hole are 98 percent for the Maquoketa and 98.8 percent for the Galena (table 10).

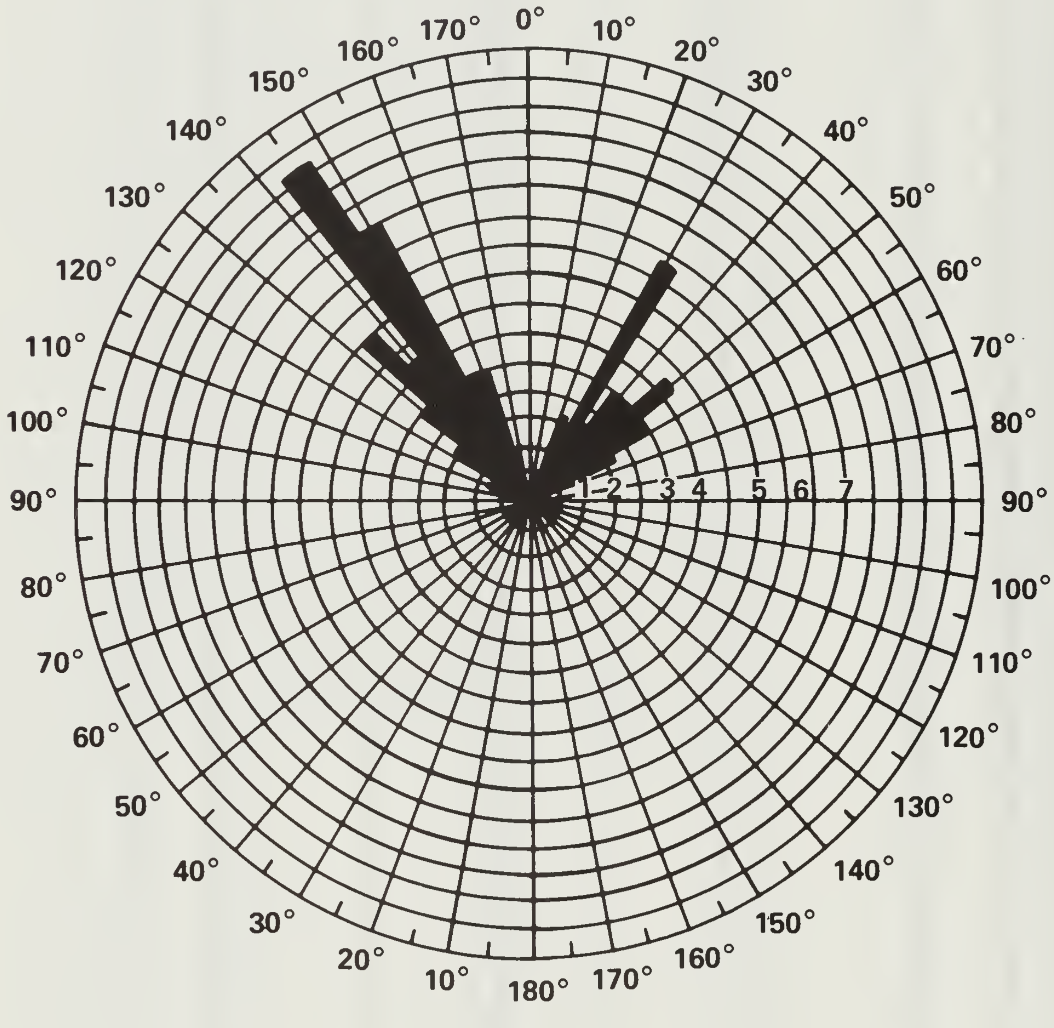


Figure 48 Strike diagram of joints in Test Hole F-8.

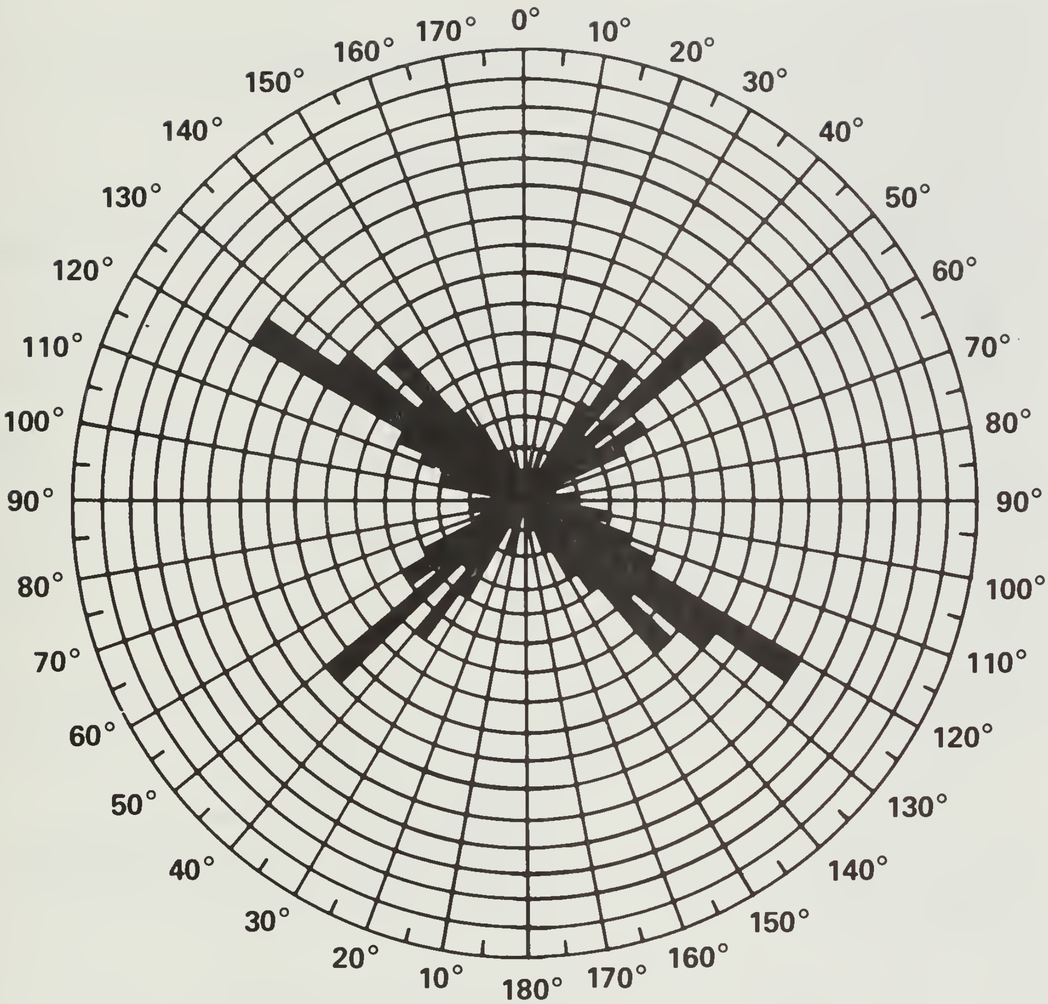


Figure 49 Regional strike patterns of joints in Meyers Material Company quarry near Big Rock, Illinois (Foote, 1982).

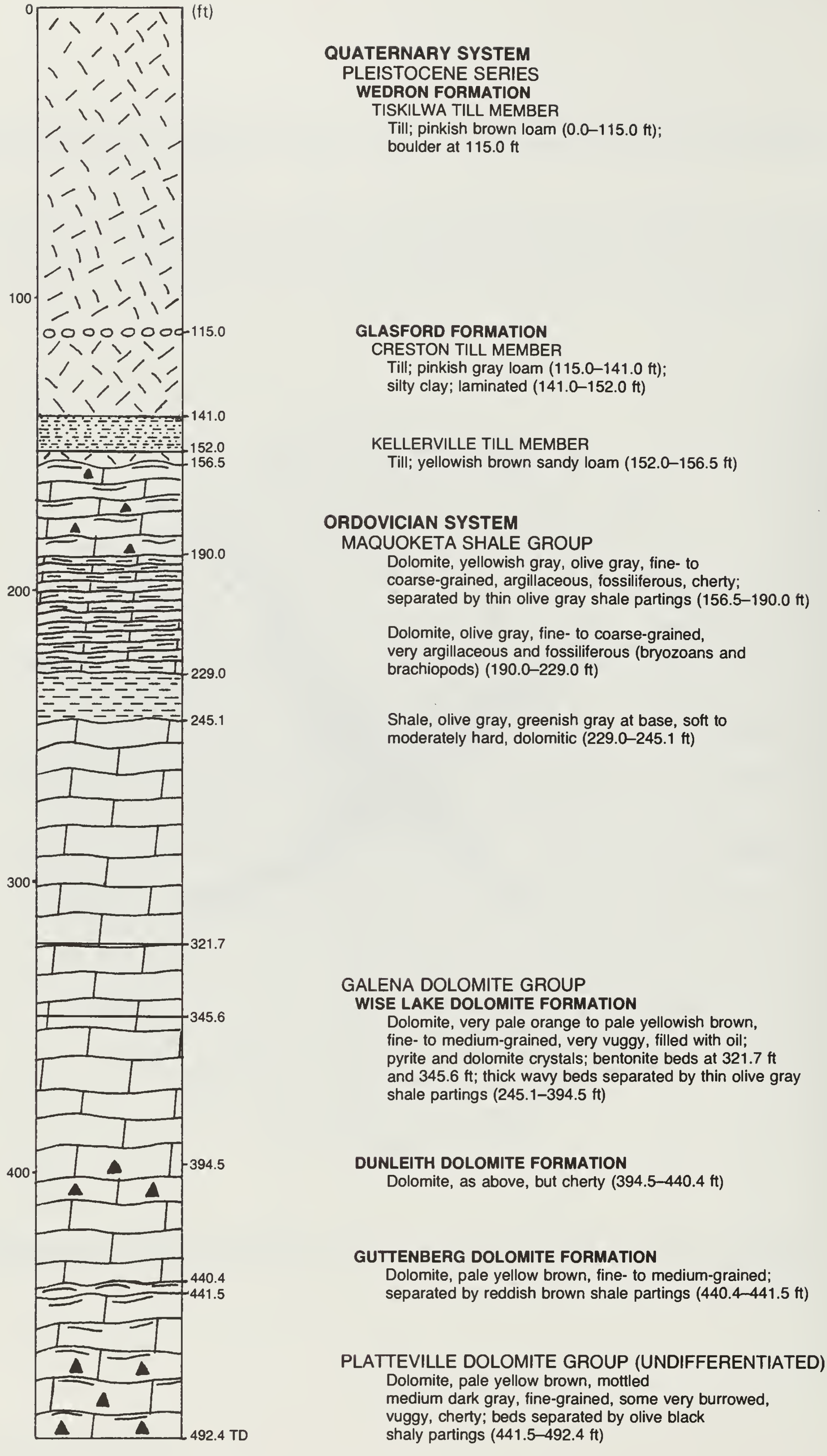


Figure 50 Stratigraphic column for Test Hole F-9.

TEST HOLE ISGS F-9

Location: SW¼ SE¼ SE¼ SE¼ Section 10, T41N, R5E
Farm: A. Turek Residence, De Kalb County
Surface elevation: 917 feet
Total depth: 492 feet

Stratigraphy

Bedrock

The stratigraphic column (fig. 50) shows the lithologies and depths to drift and bedrock units encountered in hole F-9. The hole penetrated into the top of the Platteville Dolomite Group to a total depth of 492.4 feet. The units encountered from (top to bottom) 156.5 feet of glacial drift, 88.6 feet of olive gray and greenish gray shale grading upward into light gray, fine- to coarse-grained, argillaceous, cherty, vuggy dolomite (Maquoketa Shale Group), 149.4 feet of yellowish brown, fine- to medium-grained, very vuggy dolomite (Galena Dolomite Group; Wise Lake Formation), 45.9 feet of yellowish brown, fine- to medium-grained, cherty dolomite (Galena Dolomite Group; Dunleith Dolomite Formation), 1.1 feet of yellowish brown, fine- to medium-grained dolomite with reddish brown shale partings (Galena Dolomite Group; Guttenberg Dolomite Formation), and 50.9 feet of yellowish brown, mottled dark gray, very fine-grained, slightly vuggy, cherty, dolomite (Platteville Dolomite Group; undifferentiated). Of note are two K-bentonite beds encountered at 321.6 feet and 345.6 feet in the Wise Lake Formation.

Glacial Drift

Borehole F-9 penetrated 156.5 feet of glacial drift. From top to bottom are 115.0 feet of pinkish brown loamy till, 37.0 feet of brownish to pinkish gray loamy till and clay (Glasford Formation; Creston Member), and 4.5 feet yellowish brown sandy loam till (Glasford Formation; Kellerville Member). Kellerville deposits are rare in this part of Illinois and have not been identified east of the Fox River.

F-9 is located on a northwestern part of the Elburn Complex, suggesting that perhaps the upper part of the complex in this general area is made up of the Tiskilwa, and not composed of the mixed clay composition materials of the Malden Till Member found in the southern part of the complex (Wickham, Johnson and Glass, in preparation).

Geophysical Logging

The gamma-ray neutron log clearly reflects the strata encountered (fig. 51). From total depth to 246 feet the dolomite of the Galena and Platteville Groups are observed with their characteristically low gamma emissions and low porosities indicated on the neutron log. The sharp peaks observed at 345.6 feet on both the gamma and neutron traces suggest a bentonite bed at that depth. From 246 to 188 feet the shale at the base of the Maquoketa Group exhibits high gamma emissions and high thermal neutron activity caused by the hydrogen present in the clay minerals, the dominant constituent of the shale. From 188 feet to top of bedrock at 155 feet, gamma emissions decline as shales become more dolomitic and interbedded with dolomite.

In the Pleistocene section three zones of high gamma emissions interpreted to be clay-rich glacial materials separated by less clay-rich materials (possibly sand and gravel zones) appear at 148–142 feet, 136–133 feet, and 118–115 feet. The sharp deflection to the right at 93 feet on the neutron log is the top of water in the casing. A similar deflection occurs at 94 feet on the density log.

Pressure Testing
The results of the individual pressure tests for this boring are listed in table 24, and the range of hydraulic conductivity values for test intervals are shown graphically in figure 51. Borehole F-9 had a slight water loss during drilling in the upper 50 feet of bedrock and additional water loss about 380 feet below the ground surface in the Galena.

Geotechnical Data

Bedrock
The only extensive jointed or fractured zones are two shattered, cherty sections at depths of 307 and 397 feet below the ground surface. The joints and fractures in the Maquoketa dip from 0 to 90 degrees from horizontal (fig. 52). Seventy-eight percent of the joint surfaces are wavy and 22 percent are planar. Fifty-two percent of the asperites were rough and 48 percent were smooth or slickensided. The joints in the Galena have 60- to 90-degree dips with 85 percent of the joints being vertical (fig. 53). All the joints in the Galena were wavy and rough. The joints in the Platteville dipped from 65 to 90 degrees and were wavy and rough with only one smooth joint surface (fig. 54).

The core recovery and RQD values are excellent with no core recovery values lower than 98 percent (tables 9 and 10, respectively). The lowest RQD value is 75 percent in one shattered cherty section. The average RQD values are 97 percent in the Maquoketa and 98 percent in the Galena and Platteville (table 10).

Drift
The drift at F-9 is almost compeltely loam till, but bearing capacity changes from low to medium from 0–55 feet, and from high to very high from 55–156.5 feet. Laminated clayey silt with medium to high bearing capacity was found between 135 and 143.0 feet. Engineering properties of samples from this hole are shown in table 25.

Table 24. Hydraulic conductivity (cm/sec) for Test Hole ISGS F-9 *

Test intervals (ft)	P_1	P_2	P_3	P_2	P_1
490-469	$2.9x10^{-6}$	$3.0x10^{-6}$	$6.3x10^{-6}$	$6.0x10^{-6}$	$5.9x10^{-6}$
448-427	$7.3x10^{-6}$	$1.1x10^{-5}$	$1.2x10^{-5}$	$1.1x10.^{-5}$	$1.2x10^{-5}$
427-406	$2.9x10^{-6}$	$1.7x10^{-5}$	$1.8x10^{-5}$	0	0
406-385	$1.5x10^{-6}$	$1.0x10^{-6}$	$8.0x10^{-7}$	0	0
385-364	$7.3x10^{-5}$	$7.8x10^{-5}$	$8.1x10^{-5}$	$8.8x10^{-5}$	$1.1x10^{-4}$
320-299	0	0	$1.7x10^{-5}$	0	0
259-238	0	0	0	0	0
207-186	$1.2x10^{-4}$	$1.3x10^{-4}$	$1.1x10^{-4}$	$1.1x10^{-4}$	$1.4x10^{-4}$
186-165	$4.8x10^{-6}$	$9.7x10^{-6}$	$2.7x10^{-5}$	$8.6x10^{-6}$	$1.6x10^{-6}$

* P_1 = 35 psi,

P_2 = 70 psi,

P3 = 100 psi

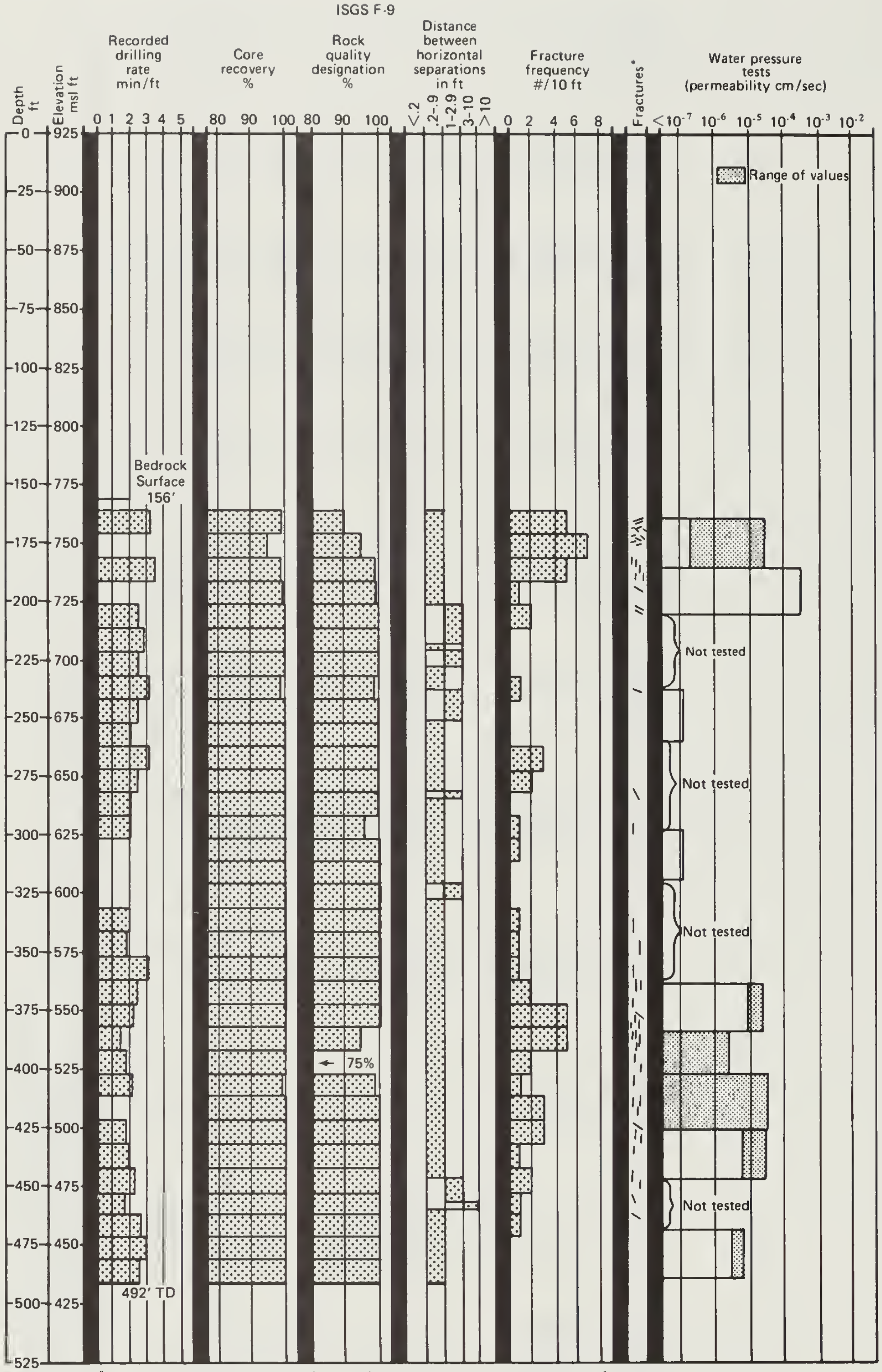
Table 25. Engineering properties of drift for Test Hole ISGS F-9

Depth of sample (ft)	Unit description	N (blows per ft)	qp⁺ (tons/ft²)	Moisture content (%)	Dry density (gm/cm³)	Moist density (gm/cm³)	Grain Size: Gvl** (%)	Grain Size: Sand* (%)	Grain Size: Silt* (%)	Grain Size: Clay* (%)	Unified soil classification
8.5-10		30	---	---	---	---	10.3	56.7	29.3	14.0	CL
13.5-15		24	2.00	11.2	2.11	2.38	3.3	31.3	40.6	28.1	CL
	pinkish			12.1							
	brown,			11.0							
18.5-20	gravel-	18	1.30	13.5	---	---	3.6	29.8	41.6	28.6	CL
23.5-25	bearing	18	0.90	12.8	---	---	4.8	30.8	42.7	26.5	CL
28.5-30	loam	18	1.25	13.4	---	---	4.5	28.1	43.2	28.7	CL
33.5-35	till	18	1.40	12.3	---	---	4.9	31.1	41.1	27.8	CL
38.5-40		26	1.25	11.8	2.14	2.32	6.6	31.0	40.0	29.0	CL
				11.8							
				12.0							
43.5-45		36	1.00	12.0	---	---	4.3	31.8	38.4	29.8	CL
48.5-50		30	1.30	11.6	---	---	5.9	32.5	37.3	30.2	CL
53.5-55		26	1.30	10.4	---	---	10.9	34.3	38.4	27.3	CL
58.5-60		36	2.50	9.9	---	---	12.5	36.7	42.0	21.3	CL
63.5-65		64	>4.50	9.5	---	---	19.2	36.8	40.9	22.3	CL
68.5-70		48	2.25	10.8	---	---	8.0	33.4	40.7	25.9	CL
73.5-75		86	---	---	---	---	---	---	---	---	CL
78.5-80		62	4.5	9.8	2.14	2.37	6.1	32.3	40.7	27.0	CL
				9.7							
				9.4							
83.5-85		78	>4.5	10.3	---	---	3.6	30.0	42.4	27.6	CL
							8.2	29.8	36.6	2.2	

Table 25. *continued*

Depth of sample (ft)	Unit description	N (blows per ft)	qp+ (tons/ft^2)	Moisture content (%)	Dry density (gm/cm^3)	Moist density (gm/cm^3)	Grain Size: Gvl** (%)	Grain Size: Sand* (%)	Grain Size: Silt* (%)	Grain Size: Clay* (%)	Unified soil classification
88.5-90	pinkish	132	>4.5	10.7	---	---	0.0	83.7	13.9	2.4	CL
93.5-95	brown	184	---	8.4	---	---	6.3	37.8	38.3	23.9	CL
98.5-100	loam till	62	2.75	9.4	---	---	9.9	35.0	38.9	26.1	CL
103.5-105		100	<-------------NO RECOVERY------------->								CL
	boulder		<-------------BOULDER------------->								
115.5-117	pinkish to	106	soft	10.0	---	---	8.1	37.5	37.2	25.3	CL
	brownish		<-------------RIBBON SAMPLE------------->								
123.5-125	gray loam	72	>4.5	9.6	2.27	2.51	14.5	45.6	32.7	21.7	CL
	till			9.7.							
133.5-135	till	164	>4.5	11.5	2.09	2.36	5.8	23.5	37.9	38.6	CL
				10.5							
143.0-144.1		90	>4.5	18.8	---	---	0.1	30.9	58.9	10.2	ML
				15.3							
	laminated			18.8							
144.1-144.5	silty clay				1.85	2.28	0.0	0.1	26.2	73.7	CL
153.5-156.5		208	>4.5	6.2	---	---	13.4	50.7	29.6	19.7	CL
	bedrock										

*percentage of < 2-mm fraction
**percentage of whole sample
+as measured by pocket penetrometer



*Fractures shown correspond to fracture frequency except where extensively fractured

Figure 51 Summary diagram for Test Hole F-9.

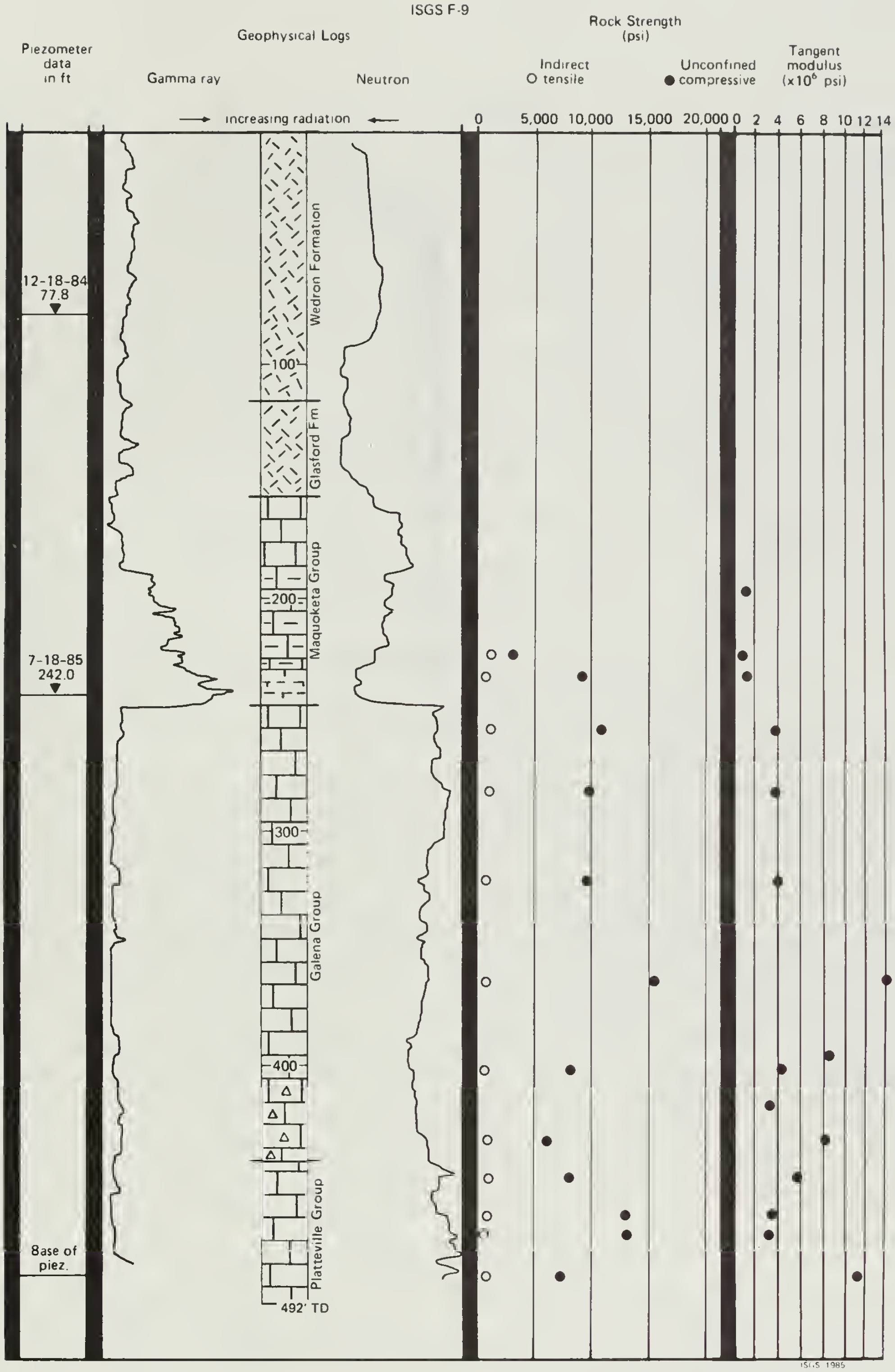


Figure 51 *continued*

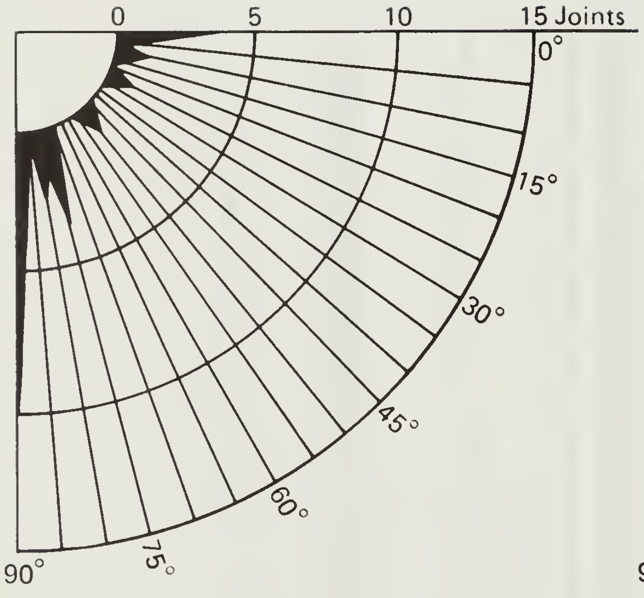


Figure 52

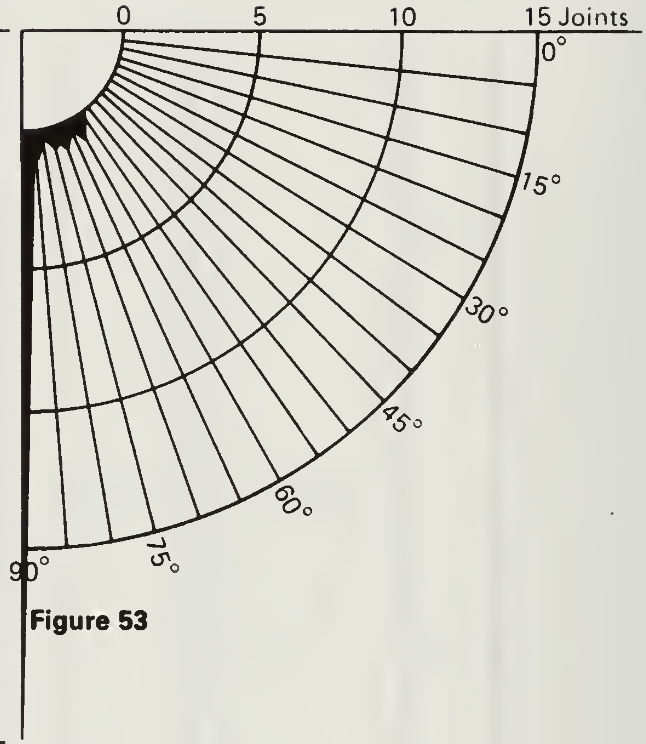


Figure 53

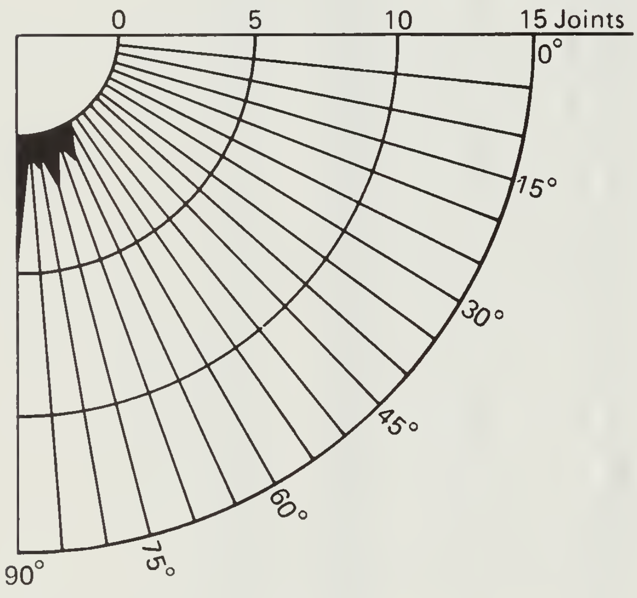


Figure 54

Dip diagrams for joints in Test Hole F-9:
52 81 feet of cored Maquoketa Group strata.
53 195 feet of cored Galena Group strata.
54 52 feet of cored Platteville Group strata.

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